This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

Soc. 1861 e. 156/7

MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. VII.

SESSION 1848.

EDITED BY

CHARLES MANBY, ASSOC. INST. C.E.,
SECRETARY.

INDEX, PAGE 419.

LONDON:
Published by the Institution,
25 GREAT GEORGE STREET, WESTMINSTER.
1848.

The Copyright of this Work is vested in the INSTITUTION OF CIVIL ENGINEERS, *and the right of Publication and of Translation, in Great Britain and in Foreign Countries, is reserved, in accordance with the provisions of the Copyright Act.*

LONDON: PRINTED BY W. CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

ADVERTISEMENT.

THE Institution is not, as a body, responsible for the facts and opinions advanced in the following Papers read, or in the abstracts of the conversations which have occurred at the Meetings during the Session.

CONTENTS.

Number of Paper.	Subjects.	Authors of Papers.	Date.	Page.
	Annual Report	. .	1848 . .	1
	Statement of the Transfers, Elections, Deceases, and Resignations, during the Years 1846 and 1847.	. .	. .	6
	Memoir of Robert Thom	. .	. .	7
	,, Francis Giles	. .	. .	9
	,, Antoine Lipkens	. .	. .	10
	,, David Mushet	. .	. .	11
	,, John Reynolds	. .	. .	12
	,, Charles Holtzapffel	. .	. .	14
	Abstract of Receipts and Expenditure . .	. .	. .	20
	Telford Premiums awarded	. .	. .	22
	Ditto subjects for	. .	. .	23
	Address of Sir John Rennie, President, to the Annual General Meeting.	Sir J. Rennie .	Jan. 18	27
	,, Joshua Field, Esq., President .	J. Field . . .	Feb. 1	32
	Original Communications, List of . . .	. .	. .	44
	Ditto Drawings, List of	. .	. .	46
	Catalogue of Presents	. .	. .	47
	List of Officers	. .	. .	56
774	Manufacture of Artificial Stone, with a Silica Base.	F. Ransome .	Jan. 11	57
	Discussion on ditto	. .	. .	59
779	Engine Counter (1 woodcut)	J. Richmond .	,,	71
	Discussion on ditto	. .	. .	72

Number of Paper.	Subjects.	Authors of Papers.	Date.	Page.
	Annual General Meeting	. .	1848 Jan. 18	73
	Election of Council	. .	. .	75
	Election of Members	. .	Feb. 1	75
780	Drainage and Sewerage of Bristol (1 plate).	J. Green . .	,, 8	76
	Discussion on ditto	. .	. .	84
783	Submarine Foundations, particularly the Screw Pile and Moorings (4 plates and 11 woodcuts).	A. Mitchell .	,, 22	108
	Discussion on ditto (3 woodcuts) . . .	. .	. .	132
525	Maplin Sand Lighthouse (1 plate) . . .	J. B. Redman*.	. .	146
	Appendix: description of the Construction.	. .	. .	153
	,, principal dimensions, scantlings, &c.	. .	. .	155
	Discussion on ditto	. .	. .	155
777	Formation of Dock Entrances, upon a Tideway (1 plate).	J. B. Redman .	,, 29	159
	Discussion on ditto (1 woodcut). . . .	. .	. .	173
	Election of Members	. .	Mar. 7	184
	Railway Money Chest (3 woodcuts). . .	J. Chubb . .	. .	185
782	Sea Defences (1 plate)	W. J. M. Rankine	,, 14	186
	Discussion on ditto	. .	. .	192
785	Railway Junctions (1 woodcut)	A. Beanlands .	,, 21	204
	Appendix: Tables	. .	. .	208
773	Engineering of the Rhine, ... and Improvements of the Moselle	G. B. W. Jackson and M. Van den Bergh	,, 28 . .	211 226
	Discussion on the Engineering of the Rhine	. .	. .	243
	Election of Members	. .	April 4	250
468	Description of the Bann Reservoirs (8 plates)	J. F. Bateman .	, 11	251
	Discussion on ditto	. .	. .	274

* Read May 24, 1842.

Number of Paper.	Subjects.	Authors of Papers.	Date.	Page.
	Elastic Metallic Piston	W. & C. Mather	1848 April 11	289
	Resolution as to holding President's Conversazione at the Institution.	"	,, 18	291
790	Resistances to Railway Trains (abstract) .	D. Gooch . .	"	292
	Discussion on ditto	"	"	294
	Election of Members	"	May 2	326
786	Motion of Shingle, Sand, &c. (2 plates). .	J. T. Harrison .	"	327
	Appendix :—Table showing the Times of High Water on Full and Change, and the Rises of Spring and Neap Tides, in feet, at different places.	"	"	358
	Discussion on the Motion of Shingle, Sand, &c.	"	"	360
	Notice of President's Conversazione . .	"	,, 30	366
	Election of Members	"	June 6	366
796	On Harbours of Refuge	Earl of Lovelace	,, 20	366
	Discussion on ditto	"	"	398
	Flexible Diaphragm Water-Valves (2 woodcuts).	T. Lambert. .	"	416
	Election of Members	"	,, 27	417
	Remarks on Close of Session	J. Field. . .	,,	418
	Index	"	"	419

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1848.

ANNUAL REPORT.

In the Annual Reports, for some years past, the Council have invariably had the pleasure of congratulating the Members on the general success and continued prosperity of the Institution, until, in fact, the opening paragraph might almost be stereotyped. On this occasion there is no deviation from the ordinary course, and they trust that their successors may have the same gratifying duty, for many years to come. It is hoped, that the present Session will be more brilliant, as well as more solidly useful, than any of its predecessors; and if, from peculiar circumstances, there be a temporary stagnation in new engineering works, the Members of all classes may employ this leisure in the production of interesting papers for the meetings. Such an opportunity will not, it is hoped, again occur for many years, and it should therefore be taken advantage of, for the benefit of the Institution.

The increased attendances of Members and Visitors, during the past Session, was not only gratifying to the Council, as demonstrating undiminished interest in the Society, but as being evidence of the necessity for the extension and alteration of the building.

It is satisfactory to find, that these improvements appear to obtain general approval, for the ordinary purposes of the meetings, and their capabilities will be further tested, by the Annual Conversazioni, which have hitherto been given at the private residences of the Presidents, being held at the house of the Institution.

Among the original communications, read during the past Session, there are several, not only of great intrinsic merit, but which induced discussions of most interesting character.

Among these may be mentioned:—"The description of the

Great North Holland Canal," by G. B. W. Jackson; "On the practical forms of Breakwaters, &c." by Scott Russell; "On the ventilation of Mines," by J. Richardson; "On the laws of Isochronism of the Balance Spring of Watches and Clocks," by C. Frodsham; "On the Improvements of Sunderland Harbour," by J. Murray; "On the expansive action of Steam," by J. M. Heppel; "A review of the proposed plans for connecting the Atlantic and Pacific Oceans by a Navigable Canal," by J. Glynn; "On the advantages of maintaining a high degree of cleanliness in Streets and Roads, &c." by J. Whitworth; "An Account of the Sea Defences of Romney Marsh," by J. Elliott; and "On the law which governs the discharge of elastic Fluids under pressure, through short tubes and orifices," by W. Froude. Medals and Premiums have been awarded for several of these papers, and the consideration of the last-mentioned communication from Mr. Froude, has only been delayed until the next Session, in order to afford the author opportunity for further experiments, upon a subject so full of interest, and which he has studied so attentively, as to induce the conviction, that useful practical results must arise from his treatment of the question.

It has frequently occurred, that in papers which have been considered deserving of being read and published, and have even had premiums awarded to them, the authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the papers, or in the consequent discussions; and it must be understood, that such papers may have medals and premiums awarded to them, on account of the science, talent, or industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the authors of the papers.

The following Medals and Premiums have been awarded:—

1. A Telford Medal, in silver, and a Council Premium of Books, to George Briant Wheeler Jackson, Assoc. Inst. C. E., for his "Account of the Great North Holland Canal."

2. A Telford Medal, in silver, and a Council Premium of Books, to Joshua Richardson, M. Inst. C. E., for his paper "On the ventilation of Mines."

3. A Telford Medal, in silver, to John Murray, M. Inst. C. E., for his "Account of the Progressive Improvements in Sunderland Harbour and the River Wear."

4. A Telford Medal, in silver, to Joseph Glynn, M. Inst. C. E., for his "Review of the Plans which have been proposed for connecting the Atlantic and Pacific Oceans by a Navigable Canal."

5. A Telford Medal, in silver, to Charles Frodsham, Assoc. Inst. C. E., for his paper "On the Laws of Isochronism of the Balance Spring, as connected with the higher order of adjustment of Watches and Chronometers."

6. A Telford Premium of Books, to James Elliot, for his "Account of the Sea Defences of Romney Marsh."

7. A Telford Premium of Books, to John Mortimer Heppel, Grad. Inst. C. E., for his paper "On the Expansive Action of Steam."

8. A Telford Premium of Books, to William Shears, Assoc. Inst. C. E., for his "Description of the Iron Gates for the Docks at Sevastopol."

9. A. Telford Premium of Books, to Captain Masters, for his "Account of the Iron Barque 'Josephine.'"

It will be observed, that in addition to the Medals awarded to Mr. Jackson and Mr. Richardson, Council Premiums of Books, of greater value than usual, were given, in order to mark more distinctly the opinion entertained of their papers, which are both of that useful character, so requisite for the meetings; one being a description, accompanied by plans and explanatory drawings, of an executed Civil Engineering work, and the other an examination of the different modes of ventilation employed in the mines of various districts. The Council feel that it is within the power of all engineers to furnish such papers, which would, in fact, be but descriptions of those objects to which their attention is constantly devoted, and they would earnestly impress upon the Members, Associates, and Graduates, the necessity of applying some small portion of their time to the task, if they would desire the Institution to retain its position among scientific societies.

In order to produce his paper accurately, Mr. Jackson passed in Holland a portion of his usual vacation, and he did the same last year (previously to his departure for India), for the purpose of collecting materials for a paper, descriptive of the engineering works on the Meuse, which will be brought forward during this Session.

Mr. Murray's description of the "Improvements of the Harbour of Sunderland and the River Wear," and Mr. Elliott's "Account of the Sea Defences of Romney Marsh," should also be classed with the preceding papers, as possessing the same useful character and inducing animated discussions.

Mr. Heppel's paper "On the Expansive Action of Steam" is less calculated for reading at the meetings, than for study in the cabinet; but it is of a nature to be generally interesting to the theoretical and the practical engineer.

Mr. Glynn's "Review of the plans which have been proposed for connecting the Atlantic and Pacific Oceans by a navigable Canal," was gladly considered by the Council, as being the first of a new class of papers which they desire to introduce at the meetings, and relating to an interesting question, upon which the author had collected valuable information with great industry.

The same may be said of Mr. Frodsham's paper "On the laws of Isochronism of the Balance Spring, as connected with the higher order of adjustment of Watches and Chronometers." The Council particularly desire to receive papers descriptive of machinery, and treating of the principles of mechanical construction, whether directly, or indirectly, connected with the practice of Civil Engineering; and it is hoped, that as Mr. Vulliamy's paper "On Railway Clocks," which was so well received, in some measure induced the production of Mr. Frodsham's communication, so the latter paper will be the precursor of many of a similar description.

Mr. Shears' "Description of the Iron Gates for the Docks at Sevastopol" was very useful, not only on account of the clear description of constructions of more than ordinary dimensions, and of the machines invented and erected for their execution; but also, as was well observed during the discussion, because "all Civil Engineers should be aware of these facilities, in order to know where they could get such work executed."*

Captain Masters' "Account of the Iron Barque 'Josephine'" was, perhaps, the paper least directly connected with Civil Engineering; being the plain statement, by a practical seaman, of the merits and demerits of a sailing vessel, constructed entirely of iron, and devoted to a peculiar service. It does, however, contain much information, which, it is hoped, will be turned to profitable use by the practical men, into whose hands it will be delivered, in the Fifth Volume of the Minutes of Proceedings. Such papers will always be as acceptable as useful, and although, in consequence of the

* *Vide* Minutes of Proceedings, 1847, vol. vi., p. 54.

lamented decease of Captain Masters, no further account of the 'Josephine' may be expected, iron is now so much employed in the construction of craft of all tonnages, that it must be in the power of many of the Members and Associates to supply interesting matter relative to the construction, the duration, and the general qualities of iron vessels.

The list of the subjects for Premiums, which has been issued for this Session, contains, in addition to several of the old subjects, many new ones, to which the Council would direct the attention of all; but, more especially, those who have not yet fulfilled the engagement entered into on their election, "to present to the Institution an original communication, drawing, plan, or model of engineering interest, or some scientific work for the library, within the space of twelve months from the date of election." It must be evident, that unless this engagement be fufilled, the interest of the meetings cannot be sustained, and the objects of the Institution must fail. The Council would, therefore, earnestly request attention to this point. They are aware that there are many, who, from some peculiar position, may be precluded for a time from writing papers; but even they may assist, or influence others, who have more leisure, or who are not fettered, and as there is a temporary cessation from the harassing pressure of employment, which has existed for some years, it is hoped, that advantage may be taken of it, to record accounts of some of those gigantic specimens of engineering skill, which are the boast and pride of this country.

The presents of books, maps, models, and specimens, have not been so numerous as usual; but the Institution continues to be indebted to the Honourable Board of Ordnance, and the Admiralty, through the Honorary Members, Major-General Colby and Admiral Beaufort, for the Ordnance maps, the Admiralty charts, and the Reports published by the Government; as also to other public Boards, for contributions to the library, as will be seen by the list of presents; among which will be found a portrait of the late Mr. Jessop, presented by his Son, at the suggestion of your member, Mr. Burges, to whom you are already indebted for the portrait of Smeaton, for which he has now found a companion.

The liberality of Mr. Wyld, M. P., should be particularly noticed. One of the gentlemen to whom a premium of books, of the value of five guineas, had been awarded, selected an Atlas; Mr. Wyld, on being informed of the circumstance, immediately ordered copies of his large Atlas, the price of which is eleven guineas, to be substituted; and, at the same time, expressed his

intentions of presenting to the Society copies of any new charts he might publish, which would be interesting to the profession.

The Minutes of Proceedings have received liberal contributions of copper-plates, wood-cuts, lithographs, and reduced drawings, not only from members, but from several editors of scientific journals, with whom the most amicable interchange of courtesies is established.

The tabular statement of the transfers, elections, deceases, and resignations of members of all classes, during the years 1846 and 1847, appears thus:—

	Honorary Members.	Members.	Associates.	Graduates.	Annual Increase.
1846. Transferred to Members .	..	..	2	4	
Transferred to Associate .	..	..	..	1	
Elections . .	..	7	23	..	30−10=20
Deceases . .	..	..	4	..	10
Resignations .	..	..	6	..	
1847. Transferred to Members. .	..	..	1	3	
Transferred to Associate. .	..	..	..	1	
Elections . .	..	8	21	..	29−19=10
Deceases . .	..	3	6	..	19
Resignations .	..	2	8	..	
Members of all classes on the Books, Dec. 31, 1847 . . .	35	214	321	40	= 610

If the Honorary Members and Graduates are omitted from the calculation, the annual increase of Members and Associates stands thus:—

Years.	Members.	Associates.	Members Elected.	Deceases, Resignations, and Erasures.	Effective Increase.
1842	8	38	46	7	39
1843	7	37	44	6	38
1844	8	36	44	42	2
1845	10	34	44	7	37
1846	7	23	30	10	20
1847	8	21	29	19	10

The deceases are more numerous than usual, and among them are valuable Members, whose memoirs are unavoidably extended to more than ordinary length; but it is felt, that although it is desirable to render these notices as succinct as possible, it is only a proper testimony of respect, to notice the principal events in the lives of those who have passed from among us.

They are Robert Thom, Francis John William Thomas Giles, and Antoine Lipkens, Members; David Mushet, John Reynolds, Charles Holtzapffel, Thomas Evans, Francis Watkins, and John Ball, Associates.

Mr. Robert Thom was born at Tarbolton, in Ayrshire, in the year 1774. His youth was spent in agricultural employments on his father's farm; but the winter months, as well as any other hours that could be gained, were devoted to the cultivation of his mind, and he thus acquired a good sound education. He then, under the instructions of an elder brother, became an expert joiner, or "wright," at which trade he worked at Glasgow, whither he removed, in the hope of advancing in life. He then (about the year 1794) turned his attention to cotton-spinning, which branch of manufacture was at that time rising into importance. Although the days were occupied in laborious employment, the evenings were devoted to attending the University lectures on mathematics, &c., and to receiving private instruction from some of the most eminent professors of the period; and he so distinguished himself, that when Mr. Lothian, Professor of Mathematics, emigrated to America, he presented Mr. Thom with his MS. papers and the notes of his lectures.

After some time, the direction of the cotton mills at Pollockshaws was offered to him, and although the consequent duties fully employed him, he found time to pursue his favourite studies, and he investigated and controverted some of the speculative views then introduced by Count Rumford.

From Pollock-shaws, Mr. Thom removed to the cotton mills at Blackburn, where he acted as the managing partner until 1817, when he became interested in, and took the direction of, the spinning mills at Rothesay, in the Island of Bute. Here was executed his first attempt at the collection of a supply of water, in reservoirs, against the dry season, which previously had always stopped the works. This he accomplished by forming an extensive system of drains, which conveyed the superabundant moisture, from the surrounding land, into the loch, there to be stored until it was required. The self-acting sluices were also used here, and in addi-

tion to the advantages to the works, the whole district was benefited by the improved system of drainage he had introduced. The result surpassed the most sanguine expectations of the ingenious and persevering projector, and naturally directed his mind to those practical hydraulic studies which have since rendered Mr. Thom so well known among Civil Engineers. His great work at Shaws-water,* near Greenock, is so well known, as to need only passing mention; but it must ever remain a model of bold conception and careful construction, well worthy of imitation.

The system of combining the production of water-power for driving machinery, with the supply of water for the public and domestic wants of large towns, was, in this case, as successfully executed as it was boldly conceived, and in the numerous public works of the same kind, for which he either gave advice, or of which he superintended the execution, he extended and perfected the details of his first plans.

In the year 1840, his connexion with the Rothesay Mills ceased, and he retired to his estate at Ascog, with the intention of passing the evening of his days in comparative repose; but he was induced to lend his advice and assistance, in combining and executing plans for the supply of water to several towns in the United Kingdom, and also to consider many foreign schemes which were submitted to him.

In all these works he adhered to the gravitation principle, and used, with success, the large filters described in the pamphlet on the Shaws-water. In the execution of the embankments of the reservoirs, he adopted the plan of construction he had found so successful in forming the extensive reservoir near Greenock, upon the site of that which had burst some years previously, and had swept away a considerable portion of the eastern suburbs of that town. This system of construction was described by Mr. Thom at a meeting of the Institution, in June, 1843.†

The barometrical observations made by Mr. Thom, the registers kept with scrupulous precision and attention, and the tables of the state of the atmosphere, the quantity of rain falling on a given extent of surface, the amount of evaporation, and other remarks on the same subjects, have already, in some degree, become known, and have been found very useful; but as he has left a mass of

---

* *Vide* "A Brief Account of the Shaws-water Scheme," &c., 8vo. Greenock, 1829.

† *Vide* Minutes of Proceedings, 1843, vol. ii., p. 191.

MS. papers, partially arranged, with a view to the publication of a work "On the supply of Water to Towns," it is hoped, that the whole will be given to the world by his son, Mr. William Thom, who has been long engaged in carrying out the plans of his father.

Mr. Thom made several interesting communications to the Institution, and whenever he came to London was an assiduous attendant at the Meetings. His loss will be severely felt by a large circle, not only of domestic, but of professional and scientific friends, by whom his talents were duly estimated.

Mr. Francis Giles was brought up as a surveyor, and was engaged for a considerable period, in the early part of his professional career, under the late Mr. Rennie, in executing those correct and beautiful surveys which have become models for the present practice. Among these, may be particularly mentioned, the surveys of the Thames, the Mersey, the Wear, and the Tyne, and of the harbours of Dover, Rye, Holyhead, Dundee, Kingstown, &c.

Among the principal engineering works executed by Mr. Giles may be named the Ivel Canal, the Lea Union Canal, and part of the Sankey Navigation; the harbours of Bridport and Courtown, and the Tidal Dock at Southampton.

He was also engaged in the Newcastle and Carlisle Railway, which comprised, at the period of its opening, some of the boldest works in the kingdom. A cutting of 102 feet deep, through the Cowran Hills, and a bridge over the River Eden, having five arches of 80 feet span, and 100 feet in height. He laid out, and in part executed, the South-Western Railway; and he also designed and executed the Guildford Railway. The Warwick Bridge, in Cumberland, which, for elegance of design, may be called his 'chef d'œuvre,' was also built under his directions, and during forty years of active professional life, he was extensively employed in many minor works, in arbitrations, and in discussions between the conservators of tidal rivers, and encroaching landowners, for which his previous extensive surveys had eminently qualified him.

He was not a very old member of the Institution, having joined it in 1842; but he was extremely attentive as a Member of the Council, was a constant attendant at the meetings, took an active part in the discussions, and contributed some valuable charts and plans to the collection.

He died on the 4th of March, 1847, in the 60th year of his age, as universally regretted, as he had been esteemed, by an extensive circle of friends.

Mynheer Antoine Lipkens was born at Maestrecht, in the year 1782. His father, who was a cloth manufacturer, afforded him such limited instruction as could be procured from the Professors of his native town; he, however, was so devoted to the pursuit of knowledge, that with some difficulty he obtained the means of travelling to Paris, with the view of being examined for election into the Ecole Polytechnique. He suffered a severe disappointment in arriving too late; but by dint of persevering solicitation he obtained permission to attend the lectures of the school. His studies were so successful, that in a short time he was placed upon the Topographical Survey of the Department of the Loire, and successively, up to the year 1813, upon those of the Cher and the Arriège. He was then temporarily employed in military engineering duties. After the establishment of peace in Europe, M. Lipkens resumed his civil position, and in 1827 was placed at the Hague, as Engineer-in-Chief of the Topographical Survey; and the zealous and talented performance of his duties induced, in the year 1831, his nomination as a Knight of the Order of the Lion of the Netherlands. He then became one of the Councillors of the Ministry of the Interior, having more especially the department of the Patents under his charge. In the duties of his office, which so perfectly accorded with his tastes, he laboured most zealously in the advancement of mechanical inventions and introductions for the benefit of his native country, and by the amenity of his manner and the soundness of his advice and opinions, he won the esteem and admiration of all those who were brought officially into contact with him.

He was sent by the Government upon several important missions, to England and other countries, to report upon public works; and his merit was acknowledged by his having conferred upon him the order of Stanislaus of Russia, and his being nominated, on his return, to posts of confidence in the Ministry of the Interior.

In conjunction with MM. Lobato and Ulenbrock, he visited France, for the purpose of fixing a standard of weights and measures, of which Commission he was nominated Inspector-in-Chief, and, with his coadjutors, MM. Simons (Assoc. Inst. C. E.) and Byerings, he devoted much attention to the great question of the drainage of the Lake of Häarlem, which is perhaps one of the most remarkable engineering works of modern times.

The self-imposed task in which he most delighted was the last of his useful career. This design, which demanded not only mind to plan, but the utmost energy and courage to prosecute, in the face of vehement prejudice and numberless obstacles, was the formation of

the Royal Academy of Civil Engineers, at Delft. He was, however, encouraged by the munificent patronage of His Royal Highness the Prince of Orange, and urged on his course by his Eminence M. Van Schimmelpenninck van der Oye, the Minister of the Interior, and in a few years he had the satisfaction of seeing his utmost expectations exceeded by the success of the pupils, and after he had ceased to be the Director of the Academy, to find, that under his worthy successor, they continued the same useful and brilliant career.

In this noble design M. Lipkens was, doubtless, greatly influenced by the example of the Institution of Civil Engineers of London, of which he became a Member in the year 1836; and not only during his visits to England; but in his correspondence, and by his attention to the Members who visited Holland, he showed how much he was interested in its advancement and prosperity.

His merit was further acknowledged, by his Sovereign, in his promotion to the rank of Commander of the Order of the Lion of the Netherlands, and when he retired into private life he bore with him, not only the public respect and esteem; but, also, that which his simple and unostentatious mind valued even more highly, the love and regard of his coadjutors and his private friends, who, in losing him found a void created in their social circle, which will not readily be filled; indeed, of such men it may with truth be said, "L'homme de bien appartient à sa famille; le grand citoyen à son pays; le savant au monde entier."

Mr. David Mushet early imbibed a taste for mineralogical and metallurgical pursuits, which he cultivated to the greatest extent, indeed, in many of his views respecting the smelting and manipulation of metals, he was far in advance of the period in which he lived, and to the result of his researches, the world is indebted for many of the improvements introduced in the iron and copper trades, and which have even been patented by other persons, without any benefit accruing to Mr. Mushet. This is, however, but too commonly the case with men of genius, who appear to be sent as pioneers, to clear the obstructions from the path of the more matter of fact, but not less meritorious, practical men, who find their industry solidly rewarded, whilst even the bare credit of the discovery, is sometimes withheld from the original inventors.

The discovery by Mr. Mushet of the black-band iron ore in Scotland, and, subsequently, in South Wales, may be given as an instance of the manufacturing prosperity of whole districts being

advanced by a discovery, which never produced him even a vote of thanks from those who were enriched by it.

His investigations into the changes during the processes of smelting and working metals were acute, and produced some good practical results; that into the causes of red-shortness and cold-shortness in bar-iron may be particularly mentioned, because of the simple and easy methods he pointed out for remedying those defects.

As an Iron Master in Scotland, in Derbyshire, and in the Forest of Dean, and during his connexion with the British Iron Company, as well as when he was consulted by various foreign Governments, and by private individuals, on practical questions, he had ample opportunities, not only for experiments on a large scale; but also for collecting information, which he used in numerous well-written and useful articles in the Encyclopedias and Periodicals, and in his Papers on Iron and Steel.*

He has left a large collection of MSS., relative to the processes of iron-making and metallurgy generally, which it is hoped some of his talented family will collate and give to the world, as there have been few experimentalists whose researches were carried on with such indefatigable industry and perseverance, and yet of whose labours so little is really known.

Mr. Mushet's career, although eminently active and useful, during stirring and eventful times, was not as fortunate as it deserved; but he was as highly esteemed by all who knew him in private life, as he was admired for his talents and acquirements in his public career.

Mr. John Reynolds was born in the year 1796, at the Ketley Iron Works, Shropshire, of which establishment his father, Mr. Joseph Reynolds, was the managing partner. He thus became, at an early age, familiar with the working of minerals, and the various processes of iron-making; he at the same time evinced considerable aptitude for mechanical combination, which was fostered by the spirit of investigation and enterprise that always distinguished the management of the Ketley Works, from their first establishment under the late Mr. Richard Reynolds.

At the age of sixteen, Mr. Reynolds was placed in the counting-house of Messrs. Rathbone, of Liverpool, whence, in a few years, he was transferred to participate in the management of the Ketley

* Papers on Iron and Steel, Practical and Experimental; a series of communications made to the Philosophical Magazine, &c., 8vo. London. Weale, 1840.

Works, until they were given up in 1818. He then became a partner in, and the manager of, the Carmarthen Tin Works, until after their removal to Aberayron, when he separated from the concern, and engaged in the erection of extensive iron works at Cwm Avon. In the prosecution of this undertaking, the peculiar characteristics of his mind were strikingly displayed, by the persevering courage with which he combated difficulties of no ordinary kind, and the skill with which he adapted his contrivances to the peculiarities of the situation. The failure of his plans developed other not less valuable traits of character; for as he bore all the trials and disappointments, incidental to a new undertaking, with hope and cheerfulness, so at last the unsuccessful result induced no despondency, and the strength and elasticity of his mind, enabled him to turn to the not less congenial pursuits of mechanical invention, and the improvement of manufacturing processes, several of which he had only been prevented from prosecuting by his ordinary occupations. Among these may be mentioned, an ingeniously contrived rotary steam engine, and improvements in paddle-wheels. He also devised some modifications of the process of manufacturing salt; but the subject to which he devoted the greatest amount of attention, was the introduction of continuous longitudinal bearings for railways, and the rejection of stone blocks. This subject he brought before the Institution on his election as an Associate in 1837; and the paper was subsequently published in the Transactions.* In the year 1834-5, the system of the angular base to the trough rail, suggested itself to him; but owing in some measure to the expense of the plan, as first designed, it was not carried to any great extent, although upon a portion of five miles in extent, on the Birmingham and Gloucester Railway, where it was tried, it answered his expectations, and was reported upon favourably by Mr. Sturge. The angular form has now been successfully adopted for cross sleepers, the continuous longitudinal bearing has been extensively employed, and the stone blocks are universally discarded.

Mr. Reynolds continued to interest himself actively in every new and great undertaking, in the mechanical world, up to the period of his decease, which occurred January 13, 1847, after an illness of only twenty-four hours.

He was a constant attendant at the Institution, and a contributor in every way to its benefit. His worth was as fully admitted by those who only met him in public, and judged of him from his

* *Vide* Transactions Inst. C. E., vol. ii., p. 73.

evident talent, as by those who knew him in private, where he was justly esteemed and admired.

Mr. Charles Holtzapffel was the partner and successor of his father, Mr. John Jacob Holtzapffel, a native of Germany, who settled in this country, about the year 1787, and attained some reputation as a manufacturer of tools for amateur mechanics, and for improvements in lathes for common and ornamental turning.

Mr. Charles Holtzapffel devoted himself assiduously to the acquirement of scientific and practical knowledge, which he applied in the direction of his father's business, in which he was associated at an early age, and he introduced into their productions many improvements. Both at that period, and subsequently, he was extensively engaged in the construction of machinery for printing bank notes, of lathes for cutting rosettes, and for ornamental and plain turning, of machines for carving, and numerous other branches of mechanic arts, as well as in constructing instruments, which, from their delicacy, should almost rather have fallen within the province of the mathematical instrument maker; of these may be mentioned—the Indicator, used by Professor Moseley and Mr. W. Pole (Assoc. Inst. C.E.) for experiments upon the engine at the East London Water-works, and which was exhibited at a meeting of the Institution,* in March, 1842.

His attention was not, however, exclusively devoted to these matters of business; he exerted himself to introduce a system of definite measures, based on the decimal sub-division of the standard inch, instead of the usual arbitrary method of working by gauges, and he found leisure to collect the materials for a voluminous work on "Turning and Mechanical Manipulation,"† of which he published two volumes, treating of the nature and quality of materials, their modes of preparation, the method of their manipulation, and the tools best adapted for all the purposes to which they can be applied. These volumes have been received in the most favourable manner, not only by the amateur mechanics, (for whose use he modestly stated that they had been written,) but by the professional mechanics and engineers, who find in them stores of information, which they, perhaps, scarcely know where else to seek for.

Mr. Holtzapffel's general character, as an upright, kind-hearted

---

* *Vide* Minutes of Proceedings, 1842, vol. ii., p. 102.

† Turning and Mechanical Manipulation, &c. By Charles Holtzapffel, Assoc. Inst., C.E. 8vo., 1843.

man, equalled his reputation in his own peculiar department, and his loss was deeply felt in the Institution, to which he was much attached, and to which, either as an Associate Member of the Council, or in any other position, he delighted to render himself actively useful.

Mr. T. Evans was well known, in the iron trade, as the manager of Sir John Guest's extensive works at Dowlais, South Wales, where he introduced several improvements in the manufacture of iron.

Mr. J. Ball's career, as a Merchant, was foreign to the views of the Institution; but he was enabled to concur with its objects, in becoming the proprietor of the extensive zinc rolling mills, at the Wenlock Basin, and by his connexion with the exportation to Poland, &c., of large quantities of machinery, for the establishment of the works of his former partner, Mr. Steinkeller, at Warsaw.

Mr. Watkins was an extensive manufacturer of philosophical instruments, many of which he exhibited at the meetings of the Institution, which he attended very assiduously, and he was always ready to devote his time to the interests of the Society.

These latter gentlemen belonged to the class of Associates, to whom the Institution is deeply indebted for uniform support and ready assistance, for which the Council feel great gratification in offering their best thanks.

The statement of the receipts and expenditure shows, that the ordinary financial position of the Institution is good; but the Council must direct attention to the subscription for the Building Fund, which, although responded to very liberally, both by donation and subscription, by the majority of the Members and Associates, has been hitherto disregarded by sixty-five Members and one hundred and twenty-six Associates, whose subscriptions would amount to the sum of £1006 : 19 : 0.

The Council would propose to call a Special General Meeting of Members and Associates to deliberate upon this position, and to devise a plan for liquidating the debt of £2722 : 6 : 6, still due on account of the building. It is suggested, that this sum should be borrowed upon the security of the lease, and the general property of the Society, and that an annual contribution should be paid by every Member and Associate, which, with the amount of fees to the Building Fund, paid by the new Members and Associates on their election, and by Graduates on their transfer, would, in a few years, pay off the entire amount, and leave the Society with good premises, free from incumbrances of any kind.

The collection of the arrears and of current subscriptions has been

satisfactory, and some of the former have been recovered that had been almost considered hopeless. The regulation, that "all annual subscriptions are due on the 1st of January of each year, and must be paid before the 1st of April of that year," is not yet properly observed, although it is very desirable that it should be strictly attended to, and much trouble would be saved, by the more general signature of the orders upon bankers for the payment of the subscription on application. These forms of orders have been generally circulated.

The amount of arrears of the unpaid subscriptions for 1847, due December 31st, is	£231	11	6
The total amount of arrears of the previous years, exclusive of 1847, is	336	8	6
Total . . .	£568	0	0

The unfortunate failure of the Bankers has occasioned a loss on the

General Fund . . .	£103	1	0
Life Composition Fund	59	17	0
Building Fund . .	7	15	8
Total . .	£170	14	8

An arrangement is made, however, by which a composition of eight shillings in the pound has been recovered, so that the actual loss is reduced to £102 : 9.

In order to guard against the recurrence of a similar event, the Council intended to propose, that the funds of the Institution should be placed in the Bank of England, or in a joint-stock bank; but to enable this to be done, a modification of the Bye-laws would be requisite.

Sec. 9, clause 1, states, that "The Treasurer shall be a Banker in the Metropolis, with whom all money belonging to the Institution shall be deposited by the Council, on account and for the use of the Institution."

After deliberation they have, however, decided upon opening an account with Messrs. Coutts & Co., and electing Edward Marjoribanks, Esq., Treasurer of the Institution.

It was announced, in the Annual Report for 1847,* that permis-

* *Vide* Minutes of Proceedings, 1847, vol. vi., p. 3.

sion had been obtained for trying a series of experiments upon the Croydon Atmospheric Railway, "for the purpose of determining the positive resistance to railway trains at different velocities, and the resistance of air in tubes." Before the experiments could be commenced, the atmospheric system had been abandoned on that Railway; it is, however, in use on the South Devon line, and it is hoped, that through the liberality of Mr. Brunel, the subject may still be brought before the Institution, and the interesting facts connected with it may obtain calm and careful investigation.

In the Eleventh Part of Weale's Quarterly Papers on Engineering, a large portion of Mr. Bateman's "Description of the Bann Reservoirs" was published, with the name of your Member, Mr. R. Mallet, appended to the engravings, which were copies of the drawings illustrating Mr. Bateman's communication. As no permission had been accorded for this publication, but on the contrary, when Mr. Mallet was permitted to have copies, a special stipulation was, as usual, made, that as the paper was intended to be published by the Institution, the copies should be solely for Mr. Mallet's own use, that gentleman was required to explain this infringement of the Bye-laws.* In his reply, he stated—"When I involved the extracts from Mr. Bateman's paper in the first of the series of papers on water power, which I long since promised to prepare for Mr. Weale, I did so in utter forgetfulness of the rule of the Society. Had it occurred to me, however, I should certainly, from its wording, not have conceived the rule to apply to any extracts, however large, but to papers considered as whole and complete." Mr. Mallet subsequently caused the following slip to be inserted in such copies of that part of Weale's Quarterly Papers as had not been previously circulated:—

"The Author of the first of the Papers on Water Power, in Mr. Weale's Quarterly Papers, published July 1847, has to express his regret at observing now, for the first time, his own name placed by the engraver as draughtsman to the drawings appertaining to the Bann Reservoirs. The merits of these drawings, as well as of the extracts given from Mr. Bateman's paper, presented some years since to the Institution of Civil Engineers, belong exclusively to that gentleman. He also wishes to take this earliest opportunity of expressing his regret at having inadvertently infringed the rule of

* Bye-laws, Sec. xiv., Clause 3.

the Institution of Civil Engineers, in having published these extracts without previous permission of Council.

"August 25, 1847."

Although Mr. Mallet has thus taken steps to rectify his error, yet the Council feel it incumbent upon them to bring the matter before the Society, particularly as there has been a formal complaint from an Associate of the Institution, that he also was not permitted to copy this same paper.

In conformity with the Bye-laws,* Sir John Rennie now retires from the chair, which he has held for three years, and Mr. Joshua Field, as "the senior Vice-President in duration of office" (and who, it should be mentioned, is the oldest member of the Institution, being one of its founders), is put in nomination as his successor.

Six names are also presented from which to select the four Vice-Presidents; and it must be observed, that the votes for the two Members who must of necessity not be elected as Vice-Presidents, will, as a matter of course, count for them as Members of Council. This course has been adopted, in order to afford for the vacant Vice-Presidentship a choice of Members, and at the same time to prevent the loss from the Council of, perhaps, some of the most valuable, as well as the most influential Members.

Some little deviation has been made in the form of the balloting paper, in order to render it clearer, and to prevent, as much as possible, the rejection of any lists by the Scrutineers.

It is essential to observe, that any lists containing a greater number of names than one President, four Vice-Presidents, ten Members, and two Associates, will be informal, and must be rejected; but that those which contain a less number of names may be received.

In the discussions at the meetings, many valuable suggestions have been made; but which have not obtained due attention, for want of opportunity, or time, on the part of those who alone possessed the power of doing what was required. For instance, the establishing a datum mark, to which all surveys and levels should have reference.† The useful suggestions alluded to are particularly recommended by the Council to the attentive consideration of the members of all classes; and they may feel assured, that by devoting their talents and energy to the public good, they will best defeat

---

* *Vide* Bye-laws, Sec. iv., Clause 1.

† *Vide* Minutes of Proceedings, 1845, vol. iv., p. 289.

all attempts to control their career and to deprive them of the just reward of their industry and perseverance. Let them remember, also, that "union is strength," and if they are true to each other, and use this Institution as the common centre and bond of unity, they may set at nought all efforts to dislodge the Civil Engineers of England from the proud eminence where their talents, their practical skill, and their probity has placed them.

The Council, in surrendering the trust committed to them, would again offer their sincere congratulations upon the progress of the past Sessions, and their earnest hope, not only for the future prospects of the Institution, but for the individual career of the members of all classes.

RECEIPTS.

Dr.	£.	s.	d.	£.	s.	d.
To Balance in the hands of the Treasurer				286	19	1
— Subscriptions and Fees:—						
Arrears	107	12	6			
Current	1,406	9	6			
Fees	99	15	0			
Life	59	17	0			
				1,673	14	0
— Sale of Publications:—						
Transactions	25	4	9			
Minutes of Proceedings	10	6	0			
				35	10	9
— Telford Fund, Dividends 2 Years				113	7	0
— Telford Premiums				1	10	6
— Council Premiums				47	10	0
— Portrait Fund				8	8	0
				£2,166	19	4

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By House, Great George-street, for Rent, &c.:—						
Rent	216	5	0			
Rates and Taxes	38	2	8			
Insurance	18	19	9			
				273	7	5
— Salaries				300	0	0
— Commission on Collection of Subscriptions				90	16	4
— Clerk, Messenger, and Housekeeper				157	8	0
— Postage and Parcels:—						
General	35	14	5			
Parcels		9	0			
				36	3	5
— Stationery, Engraving, and Printing Circulars, Cards, &c.				49	0	9
— Coals, Oil, Candles, and Gas:—						
Coals	64	10	6			
Candles	9	12	6			
				74	3	0
— Tea and Coffee				38	10	3
— Library:—						
Books	25	13	6			
Periodicals	34	2	0			
				59	15	6
— Publication:—						
Transactions and Minutes of Proceedings				619	15	6
— Furniture, Gas Fittings, Lamps, &c.				2	15	6
— Telford Premiums				34	15	6
— Council Premiums				30	12	0
— Diplomas for Members				7	13	2
— Manuscripts, Original Papers, and Drawings				13	17	6
— Portrait Fund				85	6	0
— Incidental Expenses:—						
Gratuities and Christmas Gifts	0	9	6			
Sending Invitations and Cards, and procuring Models, &c., for Conversazioni	46	5	4			
Occasional Assistance	13	4	4			
Assistance at Meetings	6	11	0			
Cleaning Windows and Sweeping Chimneys	2	2	0			
Soap, &c.	2	2	0			
Household Utensils, Repairs and Expenses	28	0	4			
				98	14	6
— Loss, by failure, of Messrs. Cockburns, Bankers,						
General Account	103	1	0			
Life Subscriptions	59	17	0			
				162	18	0
				2,135	12	4
— Balance in the hands of the Secretary				31	7	0
				£2,166	19	4

Examined and compared the above Account with the vouchers entered in the Cash Book, and find them to be correct, leaving a balance in the hands of the Secretary, of Thirty-one Pounds and Seven Shillings.—January 1st, 1848.

(Signed) THOS. HENRY WYATT, WM. NEWTON, } *Auditors.*
CHARLES MANBY, *Secretary.*

January 17th, 1848.

PREMIUMS, 1847.

THE Council of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, in Silver, and a Council Premium of Books, suitably bound and inscribed, to George Briant Wheeler Jackson, Assoc. Inst. C. E., for his "Account of the Great North Holland Canal."
2. A Telford Medal, in Silver, and a Council Premium of Books, suitably bound and inscribed, to Joshua Richardson, M. Inst. C. E., for his paper "On the Ventilation of Mines."
3. A Telford Medal, in Silver, to John Murray, M. Inst. C. E., for his "Account of the progressive improvements in Sunderland Harbour and the River Wear."
4. A Telford Medal, in Silver, to Joseph Glynn, M. Inst. C.E., for his "Review of the Plans which have been proposed for connecting the Atlantic and Pacific Oceans, by a Navigable Canal."
5. A Telford Medal, in Silver, to Charles Frodsham, Assoc. Inst. C. E., for his paper "On the Laws of Isochronism of the Balance Spring, as connected with the higher order of adjustment of Watches and Chronometers."
6. A Telford Premium of Books, suitably bound and inscribed, to James Elliott, for his "Account of the Sea Defences of Romney Marsh."
7. A Telford Premium of Books, suitably bound and inscribed, to John Mortimer Heppel, Grad. Inst. C. E., for his paper "On the Expansive Action of Steam."
8. A Telford Premium of Books, suitably bound and inscribed, to William Shears, Assoc. Inst. C. E., for his "Description of the Iron Gates for the Docks at Sevastopol."
9. A Telford Premium of Books, suitably bound and inscribed, to Captain Masters, for his "Account of the Iron Barque 'Josephine.'"

SUBJECTS FOR PREMIUMS.

SESSION 1848.

THE Council invite communications on the following, as well as other subjects, for Premiums:—

1. The best modes of combining materials, by arranging, or cementing them together, so as to insure uniformity of action from change of temperature.
2. The history of the invention and of the improvements in the construction of the Skew, or Oblique Arch, and observations on the effects of the Piers in the course of Rivers.
3. The construction of Retaining and Wharf Walls; with examples of failure, and the causes.
4. The construction of Piers, Moles, and Breakwaters, whether solid, or on arches, or floating, in a tideway.
5. The various systems of driving Piles, and of obtaining effective foundations in difficult situations.
6. The best and most economical mode of raising Large Stones, or Rocks, from the beds of Rivers or Harbours.
7. The improvement and maintenance of Harbours, both natural and artificial.
8. The arrangement of Docks to accommodate a large export and import trade, connected with inland navigation and railway transit, and with extensive warehouses; showing the methods employed for preventing the accumulation of silt, or sand, at the entrance, or within the Docks.
9. The modes of Irrigation and of Drainage adopted in the United Kingdom; or descriptions of works of a similar nature, in Holland, Spain, Italy, and other countries.
10. The movement of Shingle on exposed Beaches, and the deposition of Silt in Harbours, or at the mouths of Rivers.
11. An account of the waste, or increase of the Land, on any part of the coast of Great Britain, the nature of the Soil, the direction of the Tides, Currents, Rivers, Estuaries, &c.; with the means adopted for retarding, or preventing, the waste of the Land.
12. The conveyance of Fluids in Pipes, under Pressure, and the circumstances which usually affect the velocity of their Currents; with accounts of Water Works and Gas Works.
13. The most advantageous method of employing the power of a Stream of Water, where the height of the fall is greater than can be applied to Water Wheels of the usual construction.

14. The Drainage of Mines; exemplified by a statement of the actual condition of some of the Coalfields, or Mining Districts, of Great Britain.
15. The proposed substitutes for Gunpowder, for blasting Mines.
16. The construction of Anemometers, with self-registering Index.
17. Improvements in the construction of Girder Bridges, whether of Iron, or Timber.
18. The construction of Wrought Iron Roofs, for covering considerable areas.
19. Accounts of experiments on the strength of Trusses; directed to the determination of that form and those dimensions of the truss, by which it is equally liable to rupture in every part.
20. The comparative advantages of Iron and Wood, or of both materials combined, as employed in the construction of Steam Vessels; with drawings and descriptions.
21. The best forms for River and Sea-going Steam Vessels; with practical examples, giving the sizes of Steam Vessels of all classes, in comparison with their Engine Power, the principal dimensions of the Engines and Vessels, draught of water, tonnage, speed, consumption of fuel, and the various modes of propulsion.
22. The best method in use for giving Signals on board Steam Vessels, for preventing collisions at night and during fogs.
23. The results of the use of Tubular Boilers, and of Steam at an increased pressure, for Marine Engines.
24. The phenomena of attraction in Steam Vessels, when alongside each other, and of the effect upon their steering and their speed, when passing over shoals.
25. The best application of the principle of Expansion to the improvement of stationary, locomotive, or marine Steam Engines; with examples of the effect of such application, from actual experiment, and a description of the Engines experimented upon.
26. The term "Horse Power," as applied to Steam Engines.
27. Accounts of experiments, having for object to determine the friction of Machinery, and the power absorbed by various portions of the same Machinery under various circumstances.
28. The Economy of Railways as a means of transit; comprising the classification of the traffic, in relation to the most appropriate speeds, for the conveyance of Passengers and Merchandize.
29. The internal arrangements of the Termini and intermediate Stations of Railways, whether for Passengers, or Merchandize, and whether independent of, or connected with Inland Navigation.

30. Experiments on the Resistance to Railway Trains at different velocities.
31. The construction of Locomotive Engines; especially those modifications which enable additional power to be gained without materially increasing the weight, or unduly elevating the centre of gravity.
32. The construction of Railway Wheels and Axles, and the Bearings; treating particularly their ascertained duration and their relative friction.
33. The Electric Telegraph; the several modifications in its construction, and the various uses to which it has been applied.
34. Notice of the principal Self-acting Tools employed in the manufacture of Engines and Machines, and the effect of their introduction.
35. The most effective and best adapted Machines for bruising, or crushing the Sugar Cane, and for separating the juice from the vegetable fibre.
36. The various modes of boring Artesian Wells, and the geological formations which have been found most productive of water.
37. Memoirs and accounts of the Works and Inventions of any of the following Engineers:—Sir Hugh Middleton, Arthur Woolf, Jonathan Hornblower, Richard Trevithick, William Murdoch (of Soho), and Alexander Nimmo, or of other eminent scientific men.

Original Papers, Reports, or Designs, of these, or other eminent individuals, are particularly valuable for the Library of the Institution.

The communications must be forwarded, on or before the 31st of May, 1848, to the house of the Institution, No. 25, Great George-street, Westminster, where copies of this paper and any further information may be obtained.

CHARLES MANBY, *Secretary.*

25, *Great George-street, Westminster*, 1847.

Notice.

It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the

Papers, or in the consequent discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

Extracts from the Minutes of Council, February 23rd, 1835.

"The principal subjects for which Premiums will be given are:—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed; and which shall contain authentic details of the progress of the work. Smeaton's Account of the Edystone Lighthouse may be taken as an example.

"2dly. Models, or Drawings, with descriptions, of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

"3dly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or of instruments applicable to the purposes of Engineering, or Surveying."

Instructions for Preparing Communications.

The communications should be legibly written on foolscap paper, on the one side only of each page, leaving a margin of one inch and a half in width on the left side, in order that the sheets may be bound.

The Drawings should give as many details as may be necessary to illustrate the subject, and should be to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper.

"No person shall publish, or give his consent for the publication of any communication presented, and belonging to the Institution, without the previous consent of the Council."

Excerpt Bye-Laws Inst. C E., Sec. xiv., Clause 3.

ADDRESS OF SIR JOHN RENNIE, PRESIDENT,

TO THE

ANNUAL GENERAL MEETING,

JANUARY 18, 1848.

BEFORE we proceed to ballot for the Election of Officers, I trust that I shall be permitted to say a few words. By the clause in the Bye-Laws which provides for a biennial change of President, you are now called upon to discharge that duty. This wise resolution will, I trust, be the means of infusing, if possible, fresh vigour into the Institution, and will make every member feel that the welfare and honour of the Institution, as well as his own reputation as an Engineer, is essentially involved in the choice of an effective President and Council, and, as such, that he will strive by every means in his power to elect some one who is worthy, and who will qualify himself either for the office of President, or of a Member of Council, or for whatever office the general voice of the Institution may elect him. It is by this means alone that the Institution can flourish, and with it the Profession in general.

With this view, the Council have felt it their duty to propose for election, as President, a gentleman who was one of the founders of the Institution, and who has been always one of the staunchest promoters of its welfare; who has for many years filled the office of Vice-President with considerable ability, and who, from his universally acknowledged celebrity as a Mechanical Engineer, and his modest, amiable, and unassuming disposition, tempered with a proper degree of firmness, has rendered himself universally popular among you, and wherever he is known. The proposition of Mr. Field for President is only a just tribute of respect to that most influential, important, and distinguished body, the Mechanical Engineers of Great Britain, and must weave more firmly together the bonds of union between the civil and the mechanical departments of the profession. In selecting, therefore, Mr. Field as a proper person to fill the high and important office of President, the Council feel convinced, that you will

readily respond to their recommendation, and will elect him unanimously to that office. The House List is composed of names so well known to all in the profession, and whose merits have been so well tried, that it is quite superfluous for me to say anything further in their favour. There are many amongst them who have served you faithfully, who understand the duties of office (which is very important to your interest), and who you may be sure will not forget them.

With regard to the Institution itself, from the Report which has just been read by your Secretary, you must be gratified to find that at no period of its existence has it, upon the whole, been in a more prosperous condition than at present. Its Members are more numerous, its funds are more ample, and its papers and discussions, upon which alone its merits as a scientific body must depend, are, if anything, of a higher character and more numerous than they have been. There is only one point which at present acts as a drawback, but which, I have no doubt, will not long continue so; I mean the debt which still remains due for the increased accommodation and the improvement in the building which you see around you, which was called for by the increasing wants of the Institution, and which you unanimously approved, and, indeed, you scarcely considered that the Council had gone far enough. I feel confident, therefore, that you will soon relieve yourselves from the remainder of the debt, by complying with the recommendation of the Council; and I think you will admit, also, that there is no scientific Society in this great metropolis which is so well accommodated, at such a small cost, as you are; indeed, in this respect, if I may use the term, we are the envy of the scientific world. So far, therefore, we stand well in every respect, and it behoves us all to use our utmost endeavours, not only to enable the Institution to maintain its present position, but to advance its interests and to extend its influence; and nothing will tend more effectually to produce this most desirable result than well-written papers and well-maintained discussions, upon the numerous and multifarious subjects arising out of the vast number of great works in all the departments of Engineering, which have been recently executed, and of which no detailed account has been given; but which, if described in a proper manner, as those who have had the direction of them are so capable of doing, would contribute materially to the benefit of the profession, as well as of this Institution; and to this point I would direct the particular attention of all the different classes composing this Institution.

Every one has it in his power to contribute, either by way

of original written communications, or in taking part in the discussions; and, by thus recording the various facts as they have occurred in different works, the consequences derived from them, the mode adopted in treating them, the result of that treatment, and the general conclusions which may be drawn from them, and which may be applicable elsewhere under similar circumstances, we shall accumulate such a mass of information, that we shall find no difficulty in modifying these principles, so as to render them applicable to new cases, and thus to render each work, as it were, a stepping-stone, to advance still further in the paths of science. It is only by this system that we can make real progress; for if we allow the information of every member to die with him, we derive no advantage from experience. At each new work the same difficulties meet us, and the same laborious process of overcoming them, must be encountered; but, by pursuing steadily the opposite course, the obstacles to our progress continually diminish, and the attainment of a successful result becomes certain.

Looking at the position we have attained, the great progress which has been made in Civil Engineering, the numerous useful works which have been executed, the increased stimulus which they have given to the civilization of mankind, and the universal attention which has been attracted towards our profession, it becomes most important, that we should not retrograde; but that we should continue our career steadily in advance, leaving nothing undone, so long as there is anything to do, and in this way we may turn to our ultimate benefit the general stagnation which at present pervades Engineering, in common with almost every other profession. We have to look back and reflect upon what has been passed, and to consider whether, under similar cases, we might not devise some improvements; and thus, when the busy time comes again, as I anticipate will shortly be the case, we shall return to our task with renewed vigour and ability, better fitted for overcoming the numerous obstacles we may have to encounter, with greater advantage to our employers and benefit to ourselves, and thus from evil we may derive good.

Another reason for exerting our energies is, that we have many competitors in the field, and can only maintain our pre-eminence by showing ourselves worthy of it. The eyes of the world are upon us; the operations upon which we are employed are upon such a vast scale, and are so connected, in their various ramifications, with the whole range of science appertaining to civilized life, and affecting the different classes of the community at large, in their

most vital interests, that we must not be surprised if the public entertain a certain degree of jealousy and doubt.

Of late there seems to have arisen a feeling, that we, or rather the works on which we are employed, should, to a certain extent, come under the control and cognizance of the Government. Hence have arisen Railway, Tidal-Harbour, and Sanitary Boards; and perhaps, ere long, we may expect to have others established. I say we must not be surprised at this; for we cannot altogether allay apprehension, unless every possible precaution be taken to show the public that there is no occasion for it, and that their interests will be properly looked after. Such, however, being the fact, let us endeavour by every means in our power to assist the Government and their constituted authorities, in carrying out enlightened and comprehensive improvements, for the benefit of the public, without, at the same time, sacrificing the dignity of the profession, or detracting from our importance as a scientific body. Let us make the demand for our services indispensable, by our superior knowledge and information, connected with every department of our profession and by our gentlemanlike and high-minded deportment. If we steadily pursue this line of conduct, the Government will, I am convinced, act towards us in a corresponding liberal manner, and will request our services and co-operation; in fact, they will find it their interest to do so. It will not be found an easy matter to train a corps of Civil Engineers, without paying rather too dearly for the experience, and the public (who have now attained considerable insight into engineering matters, particularly the expenditure) may not approve of the cost, when they know, that the experience can be attained unaccompanied by the blunders and failures inevitably attendant upon almost all first attempts. I am sure that the Government must feel convinced of this, and will act upon it and support us. If, however, I should be deceived, and a contrary practice should prevail for a time, depend upon it, in the end, all will be right again, if we are true to ourselves and render ourselves worthy of encouragement. I repeat that our fate is in our own hands; if we act uprightly, depend upon it we shall succeed, if otherwise, it will be our own faults, and we shall deservedly fail.

And now, Gentlemen, let me take leave of you. I came among you without solicitation, on my part; not that I should wish for a moment to convey by these words the most distant idea of disrespect; but to express to you how doubly gratifying it has been to me, to have been elected to the high and distinguished post of President of the Engineers of this Empire, by the spontaneous

feeling, and, I may say, by your almost unanimous choice. This great honour, unexpected and undeserved on my part, Gentlemen, I can assure you I am most deeply sensible of, and shall continue to feel to the latest period of my existence. I have passed some of the proudest, the brightest, and happiest days of my life in the Chair of this Institution; still I feel how manifold have been my infirmities, and how very imperfectly I have discharged the arduous duties which belong to the important office of President; indeed nothing should have induced me to undertake them, but a firm reliance upon that uniform kindness and support which prompted you, in the first instance, to select me for the office of President, and in the second, to continue that kindness during the period I have filled the chair, and in this I am proud to say that I have not been disappointed. Gentlemen, if I have in any manner discharged the duties to your satisfaction, it is entirely owing, not to any talent of mine, but to your indulgence and your forbearance, for which I beg to tender you my most grateful thanks.

To the Vice-Presidents and to the Council I am most deeply indebted, for their constant and unwearied attention to the affairs of the Institution, and for their assistance and courtesy to myself;—to your invaluable and indefatigable Secretary, Mr. Manby—to Mr. Ritherdon, and the rest of the Officers, who have invariably endeavoured to their utmost to advance your interests, and to meet my wishes, my thanks are cordially tendered; and I can only add, by way of conclusion, that if I can at any time contribute in the smallest degree towards promoting the interests of the Institution, or of any of its Members, it will be a source of the most sincere gratification to me; and although my connexion with the Institution, as its President, now terminates, I would sincerely express the hope, that the not less endearing ties of friend, companion, and colleague, will not be severed, but will unite us together more firmly than before.

ADDRESS OF JOSHUA FIELD, ESQ., PRESIDENT.

FEBRUARY 1, 1848.

I BEG to assure you that I estimate very highly the honour of being elected your President, and, although I feel unequal to the task your kindness has called upon me to perform, and cannot promise to fulfil the duties in the brilliant manner they have been performed by my predecessors, I accept the post, with the firm intention of devoting my best energies to your service; relying, at the same time, on the support and indulgence of those personal friends and the adherents of the Society whom I am delighted to now see around me.

The opening of a session of this Institution has, from the period of its formation. been an epoch of gratification to me, as bringing together, more frequently, those friends whose esteem I prize, and in whose pursuits I feel an ardent sympathy. But at no time has this feeling been so strong as upon the present occasion: for, as one of the founders of the Institution, I may be permitted to feel more than ordinary pride, in seeing the association of six young engineers,* who, in the year 1818, met occasionally, in the evening, to discuss mechanical subjects, expanded in the course of twenty-nine years into a society consisting of upwards of six hundred members of all classes, and comprising nearly all the engineers of eminence in Great Britain.

As I am the first President selected from that class of engineers, whose attention has been more particularly devoted to purely mechanical pursuits and the construction of machinery, I feel it necessary to consider briefly the intimate connexion necessarily existing between the Mechanical and the Civil Engineer, and to endeavour to trace their mutual relation and dependence upon each other, reminding both classes, that here they may meet, free from the restraints of commercial interests, or rival jealousies, vying only in their love of the subjects brought before the meetings, and in their zeal in behalf of an Institution, where an unrestrained exchange of

* Henry R. Palmer, Joshua Field, William Maudslay, James Jones, Charles Collinge, and Henry Ashwell.

ideas may take place, whence useful information may be spread for the general good, and where the display of talent of all kinds will ever be duly appreciated.

Without at all pretending to claim more for my order, than will, I believe, be freely conceded, I think it must be admitted, that the Mechanical Engineer was the first to apply the great powers of Nature to the wants, the convenience, and the happiness of mankind. Machines were early invented, for aiding manual labour in lifting heavy bodies; mills were built for grinding corn and other articles; machinery was constructed for raising water from mines, for working metals, and for many other purposes, which could not have been effectually performed without such aids.

The powers of wind and water were applied to actuate these various machines; and although the application was limited in extent, in consequence of its being necessarily confined to places where those powers could be obtained, yet considerable talent and great perseverance may be discerned in the labours of the early Engineers.

At length the steam engine, at first confined to draining mines, was improved and adapted by Watt and others to drive machinery in every situation. This gave a new impulse to mechanical invention, and rapid strides were made in a few years to diminish manual labour, and to introduce machinery into the staple manufactures of the country.

An infinite variety of beautiful and useful mechanical contrivances have naturally resulted, affording employment to thousands, and increasing the national wealth; at the same time, improving and elevating the condition of the labouring classes, and increasing the comforts and happiness of all. These were the results of the labours of the Mechanical Engineer; but when an enormous increase in the quantity of the goods so manufactured, demanded more ample means of transporting them to distant markets, it became necessary to improve the public roads, then to excavate canals, from those parts of the country where coal and minerals were found, and to construct and extend harbours and docks in our great sea-ports, to facilitate the shipment of our manufactures to distant climes.

These enterprises were beyond the power of individuals, and could only be effectually undertaken by the Government, by corporations, or by joint-stock companies. It then became necessary to commit the execution of such works to some master mind, conversant both with the theory and practice of engineering. These men were, for the most part, selected from among the most eminent mechanics, and it was their duty to direct and combine the efforts

of the miner, the millwright, the mason, and the mechanic. Such men were required to possess thorough practical knowledge, with a more than ordinary amount of theoretical acquirements, enlarged and comprehensive views of the progress of society, and general business habits. As public works increased, this division of labour became more evidently necessary, and a separate class of Engineers was established, who were called "Civil Engineers," in contradistinction from "Military Engineers," whose education and pursuits adapt them solely for directing operations connected with war.

Anterior, however, to the period here alluded to, some great and valuable engineering works were executed, both in this and other countries, reflecting great credit upon those by whom they were superintended. These were generally executed by architects, or surveyors; and, without depreciating them, it may be said, that they are wanting in that mechanical skill and the arrangement and combination of materials, which characterize the works of the present day.

The Civil Engineer is now required to possess a competent practical knowledge of the mechanical branches, so that employment in a workshop should form the early part of his education, and is always found very conducive to his future success. In fact, it is only by the combination of talents and acquirements of all kinds, that the gigantic undertakings of this country have been executed, and the mighty works which are now in progress can be perfected.

Many of these great works have sprung out of the mechanical improvements of the age. The steam engine may indeed be called the prime mover and parent machine of all; and since its application to travelling, both by sea and land, some of the most stupendous works in Civil Engineering, the world ever saw, have sprung into being, and the same cause is daily leading to others, to which even the imagination can set no bounds.

The progressive improvements in the manufacture of iron in this country, with the powerful rolling mills, prepared the way for the production of thousands of miles of railway bars, whilst the locomotive engine furnished the motive power, and hence our railways, with all the mighty works connected with them; the lofty embankments; the deep cuttings; the tunnels; the viaducts; the bridges of brick, stone, cast-iron, and wrought-iron; the arrangements at the stations; and all other works connected with what is now nearly the only means of passenger transit in this country. I may also mention the wrought-iron tubular tunnel bridges now in course of erection in North Wales. These latter works possess extraordinary novelty, calling forth in a remarkable degree, the combined

skill and science, both of the Civil and the Practical Mechanical Engineer; and as they are very near completion, I may venture to express a hope, that the Institution will receive descriptions of them during the present session.

The application of the steam engine to navigation, which was commenced about thirty years ago, has brought this invaluable machine so prominently before the public, that its powers are now in constant requisition; every person of education is more, or less, acquainted with its principles and construction, and a general interest is felt in its improvement.

Steam navigation has already made very rapid strides, producing the most beneficial effects, by the speedy and easy communication it affords. The whole world is thus becoming comparatively one family, whose common interests will be universal peace, and whose objects will be the diffusion of moral, religious, and scientific knowledge. Our commercial relations will be extended, the commodities of every clime will be brought to our doors, and markets will be found for the unlimited productions of our national industry and manufacturing skill.

The engineering department of steam navigation has been wholly in the hands of the Mechanical Engineer; but its development has demanded extensively the aid of the Civil Engineer, in the improvement of rivers and of harbours, in the formation and extension of docks and landing-places, and the erection of light-houses and harbours of refuge, which are now imperatively called for, not only for the use of coasting steamers, with their valuable cargoes, but for our national protection from foreign aggression. Should that ever take place, the steam-engine will be regarded as our chief ally.

Ship-building in iron is a new art, which has been also mainly assisted by the labours of the Mechanical Engineer. The improvement of the powerful rolling-mills enabled not only larger and thicker plates to be produced; but also the angle iron and other bars of peculiar forms, for the ribs, beams, and other parts of ships. Artificers were by degrees formed in the engineering establishments, and boiler-makers became shipwrights. These adventitious aids conspired to render more general the substitution of iron for timber, in ship-building, and although iron vessels, when they were first introduced, were regarded with doubt, and even with incredulity, sufficient evidence now exists for their construction being considered the safest, as well as the most durable; they have given proof of their superior strength for resisting the violence of the sea, and enduring for months, without material injury (when

stranded), gales which would in a few days, nay, in a few hours, have reduced to fragments the stoutest timber-built ship.

The same exercise of mechanical skill and science has, under the direction of the Civil Engineer, greatly contributed to carry into successful practice numerous scientific discoveries, which, without the practical aid of the mechanic, would have existed in theory only. The supply of towns with water and gas may be mentioned as two striking instances. The former has been long known and practised to a limited extent; but it is only within the last half century, by the introduction of the steam-engine for pumping, and the use of pipes of cast-iron and drawn lead, with numerous minor accessories, that towns have been copiously supplied, to any altitude, promoting the health, comfort, and safety of the inhabitants.

Gas lighting, which is more recent, when first proposed and attempted, was supposed to be so beset with difficulties, that the scientific men of that period considered them insurmountable; they have all, nevertheless, been completely overcome by practical men, and gas light is become not only nearly universal, but almost a necessary of life. The extension of gas-lighting was greatly facilitated by the invention of welded wrought-iron tubes, which manufacture was created by the demand for this and for other requirements of the present day; in fact without their aid the application of gas could scarcely have become so general, or so extensive.

In tracing the improvements in the mechanical department of engineering, it will be found, that forty, or fifty years ago, the tools employed were very limited in number, and bad in construction and design. Of the few establishments then existing for constructing machinery, that of Messrs. Boulton and Watt was the largest; but their tools and apparatus were very limited and simple, when compared with the requirements of the present period.

The mills, and the machinery employed in them, had been hitherto chiefly constructed on the spot, by millwrights, who were a clever class of workmen, somewhat exclusive in their views, and trained chiefly to work in wood, as cast-iron was then but just beginning to be used in machinery. When, therefore, the millwrights were compelled to change their materials and tools, the least possible amount of turning, drilling, chipping, and filing was bestowed upon their work, and the labour was for the most part performed on the spot where the mill was erecting; consequently they could obtain but little aid from tools, or apparatus.

The rapid introduction of cast-iron, together with the invention of new machines and new processes, called for more workmen than the millwright's class could supply, and men trained more in the

working of iron were brought into the field. A new class of workmen was formed, and manufacturing establishments arose, to which were attached iron and brass foundries, with tools and machines for constructing machinery of every description. Among the early establishments of the kind in London may be mentioned those of Mr. Bramah, Mr. Maudslay, and Mr. Braithwaite. These engineers began a new course, improving the tools, and executing work upon a better system. Mr. Bramah not only gave the world many important and useful inventions, but executed them in a superior manner, improving the methods heretofore in use, and in his establishment the first slide rest was applied to a lathe, for general turning. Mr. Maudslay, at the same time, made great improvements in all the working tools, and his lathes were far superior to any thing known at that period. He introduced the general use of the sliding rest throughout his manufactory. He also improved the method of cutting screws. His taps and dies were arranged with regard to the proportion of the thread to the diameter; and he formed the taps and dies to cut, so that cast-iron could be tapped with ease and certainty. It was with these improved tools that the block machinery of Sir Isambard Brunel was executed, and without their aid such machines could scarcely have been constructed. The design and execution of these machines reflect almost equal credit upon the inventor and the constructor; and if they are examined at the present time, they will be found not only unrivalled in workmanship; but embodying most of the important elements of the improved tools and machines of the present day. The self-acting principle is in them first carried out, both for cylindrical and face turning; and in the morticing machine can be traced the key-grooving engine, now applied to cut iron instead of wood. The same may be said of various other tools for cutting iron, brass, and wood.

From this period a new system of working began, and was extended to the manufacturing towns. Mr. Fox, of Derby, early commenced manufacturing excellent self-acting slide-lathes, and subsequently planing-machines. Tool-making became a distinct trade, and the effect of these improved tools was soon evident, in the greater precision of the machines executed by them. The steam-engine, which had hitherto been rather a ponderous machine, with wooden beams and black iron-work, then obtained bright cylinder covers with polished parallel motions and iron-work, and every part displayed better workmanship. The castings were better executed, more ornament was introduced, and in fact the steam-engine be-

came as much improved in appearance, as it was really better in all its working parts.

With augmented power of production, an increasing demand for machinery has sprung up, and establishments for making tools have been formed, which can scarcely supply the demand upon their productive powers. We are deeply indebted to Messrs. Roberts, Fairbairn, Whitworth, Lewis, Nasmyth, and others, who have produced, and are producing, such various tools and machines, that hand-labour is being superseded, and an engineer's establishment must now possess a machine for every operation; for without such aid he is unable to compete with his rivals either in price, in time, or in the perfection of the workmanship.

Since the steam-engine has become the motive power for the present rapid travelling, both by land and water, and its weight must be conveyed the whole journey, or voyage, it is important, that it should be constructed not only upon the best principles; but that the greatest amount of power should be combined with the smallest amount of weight and space. This observation applies equally to locomotive and to marine engines; but, leaving the details of locomotive engines, I would confine my remarks more particularly to the marine engine and steam navigation, to which, from its commencement in 1816, my attention has been especially directed.

It is interesting to trace the progress of this branch of scientific discovery, and to observe, that within the last thirty years, from the early efforts for navigating canals and rivers, it has now become an essential part of our naval and commercial system, and now appears more than ever likely to absorb the whole.

In the first adaptation of the steam-engine to navigation there were many difficulties to be overcome; it was necessary to change the arrangements of its parts, to suit its novel position on board a vessel, and to render it more compact, without interfering with its working powers. The boiler was perhaps the most difficult part, and numerous errors were committed in the early attempts, until experience settled the proportions and the modes of construction, and adapted it to the service it had to perform.

The successful navigation of rivers and the coasts, and crossing the British Channel, gradually gave confidence, and longer voyages were attempted.

In 1825 the 'Enterprise' was fitted out, and proceeded round the Cape of Good Hope to the East Indies. In this vessel several contrivances were introduced, for adapting it to ocean navigation; part of the fuel was carried in wrought-iron tanks, which, as the coal

was used, were filled with water, that the vessel might have as nearly as possible the same depth of immersion; facilities were provided for holding, or turning the paddle-wheels, to repair the boards in rough weather, or to take off the floats, when a fair wind enabled the vessel to sail under canvas alone. Methods were also introduced to prevent salt from being deposited in the boiler.

These and other introductions were further improved and extended, in the numerous vessels which were built for the long sea voyages, until the year 1835, when the 'Great Western' was established, for the passage between England and New York. Since that time, above twenty steam-vessels are regularly engaged in crossing the Atlantic. The voyage to the East Indies and to China, are now regularly performed by steam, and shortly Australia will be reached in the same manner.

The first iron steam-vessel was constructed in the year 1820, by Mr. Aaron Manby, at the Horsley Iron Works. It was put togegether in London by Mr. Charles Manby (our esteemed Secretary,) and navigated by Sir Charles Napier from the Thames, across the Channel, and directly up the Seine to Paris. Others were subsequently built by the same gentlemen, and are still at work, and in good preservation.

In 1830, Messrs. Maudslay and Co. built and fitted out four iron steamers and four tow-boats for the East India Company; they were sent out to India in pieces, and were used for navigating the Ganges. About four years subsequently, six others were constructed, and all are at work at the present time. All these ten vessels were fitted with oscillating engines of sixty H.P.

Iron ship-building has since become a separate branch of construction, and within the last ten years an immense number of iron steam-vessels have been built, both for river and sea navigation, some of them of very considerable tonnage, and others of the finest forms, fitted with engines of light construction and great power, which have attained rates of speed that had hitherto been deemed unattainable.

A detailed account of the steps, by which changes have been introduced into steam navigation, would occupy too much time, and be foreign to my intention in addressing you; but I may, perhaps, advantageously allude to some of the more marked improvements, both in the engines and the vessels, by which they have been adapted to their peculiar service, whether for carrying cargo and fuel for long voyages, or for attaining great speed in short voyages.

As the vessel is required to be of the finest form, and to be built of the lightest materials, iron is employed, because ships of that

material are found to be lighter and stronger than wooden carvel built vessels of the same tonnage, and for this reason they have now almost entirely superseded timber ships, for the rapid packet service. They are usually built with water-tight bulk-heads, forming compartments, so that the ship will still float, if one division only be injured.

Several light timber vessels have been recently built of three thicknesses of plank, the two inner courses crossing each other at an inclination of 45°, and the outer course laid fore and aft. They have been generally successful, but the system has not yet been sufficiently tested, to determine the comparative strength and durability of the vessels, as compared with those built of iron.

Vessels intended for speed should not be deeper than is necessary, for the accommodation of passengers and to render them sea-worthy. Conveying a cargo in such vessels is out of the question, and in fact, all they can be expected to carry, in addition to the passengers, is their engine and the coal for the voyage; the rigging should be very light and simple, as sails usually afford very little aid, and standing rigging is always objectionable when under steam alone. In the engine, the main object is to obtain the greatest amount of power with the least weight of machinery, consuming and conveying the smallest quantity of fuel; for, as both the engine and the fuel must be carried in the vessel, excess of weight is a virtual reduction of power. To meet this requirement, all the working parts, and many of the standing parts of the engine, are constructed of wrought iron. The steam passages and other parts, and, in fact, all parts of the machine are now better proportioned, and have been rendered more compact. The introduction of feathering float-boards, prevents considerable waste of the motive power; particularly in rough weather.

The saving of space is a great consideration; for as all excess of weight in the machinery reduces the effective power, so the space taken up by the engine takes from the useful tonnage of the vessel. This has induced many very ingenious arrangements, by which the engine is rendered very compact and simple. Wrought iron, being more generally used, has enabled numerous important modifications to be introduced, all of which tend to the main objects, lightness, power, and strength.

Perhaps nothing rendered such efficient aid in the attainment of these objects, as the introduction of the tubular boiler; indeed, the high speed now attained may be said to be mainly, if not entirely, dependant upon the boiler. This is not from the steam being generated by tubes, instead of flues; but from the tubes being able to bear extreme pressure, and the shell, or case, being so much reduced

in size, is more readily braced together by stays, and thereby rendered much stronger, so that instead of being only capable of sustaining a pressure of 5 lbs. or 6 lbs. on the square inch, which was seldom exceeded with the old form of flue boilers, they can now be worked up to 15 lbs. or 20 lbs. on the square inch; and without this, no steam vessel can compete in speed with its rivals. At the same time, greater perfection of workmanship became necessary; for it is evident, the parts of the engine and boiler are more severely tried by higher pressure of steam; and as it becomes more evident, that the speed attained is, *cæteris paribus*, in the exact ratio of the pressure of steam employed, so we must expect, that the public, who are now accustomed to the velocity of railway travelling, will exact corresponding exertions from the builders of steamers, who can only protect themselves by the most scrupulous attention to the quality of the material, its proper distribution, and the good workmanship bestowed upon the machines.

The prevalence of this general feeling in favour of rapid transit, is perhaps in some degree to be regretted, although it cannot be denied, that many arguments may be urged in its favour; but, being established, it must take its course, and it only remains to take every precaution called for by the exigencies of the cases. Most particularly, it is to be hoped, that all who construct boilers to bear increased pressure, will pay the utmost attention to properly staying every part; for one weak point may lead to the most fatal accidents. It is a safe method to prove every boiler with water, to three, or four times the working pressure, and to examine every part while undergoing the operation of proof. I feel so strongly the necessity for this precautionary measure, that, even at the risk of wearying you, I must impress it strenuously upon all, for I know that in the multiplicity of business engagements this point has been overlooked, and frightful accidents have ensued.

Brass and iron tubes are now manufactured with a high degree of perfection, to meet the present demand for them; and great ameliorations have been made in the quality and the method of making boiler plates; and thus tubular boilers, although perhaps still susceptible of improvement, are already very superior to the old flue boilers, in working capability, and only require a little further amelioration to increase their durability. Whatever defects, in this respect, they may possess, must in a great degree be attributed to their being more heavily worked; we may, however, confidently look forward to the difficulties being overcome, and that this form will be the standard boiler for steam navigation.

In steam navigation, for long voyages, another great consideration is the reduction of the consumption of fuel. This can be done only by the using engines and boilers of the best construction; and presuming the engines and boilers to have this attention bestowed upon them, this desideratum can only be attained by working the steam expansively. It is not possible to carry this system to the same extent, in marine engines, as in the Cornish pumping engines, in which the grand condition is, that the engine shall be worked at much less than its ultimate power; nevertheless much may be done, and the steam-vessels of the Government, and some of those of the large companies, are working on that principle, with great advantage, and indeed it is essential on long voyages, where the coaling stations are at considerable distances apart. A large engine, worked at a subdued rate, will give out much more power for each ton of fuel, than when it is worked to its greatest effort. As an example, suppose that on board a given vessel the coals weigh 600 tons, and the engine 400 tons, a total weight of 1000 tons, the same vessel may be driven as far and as fast by 500 tons of coals, if the engine weigh 500 tons, and be worked expansively; therefore there is a manifest economy of 100 tons of coal.

The last introduction to steam navigation is the screw propeller. This, although long known, has only recently been brought to successful practice, and even now can only be considered to be in course of experiment; still the results obtained warrant our saying, that as a mode of propelling, it is equal to the paddle-wheel; the power being the same. Its application to ships of war is being already carried into effect, and the machinery is so contrived as to be below the water line and out of the reach of shot. It is confidently expected, that in the event of war, or invasion, one such ship will be equal to two ordinary vessels of war, and be of essential service both in offensive, and defensive operations.

Another and very important application of the screw propeller is as an auxiliary power on board a sailing ship; and it is found, that a small engine, of one horse power to every 10 tons burthen, in a well-formed and appointed schooner, will drive her seven or eight miles per hour in a calm, and with the aid of sails, will enable her to equal in speed a powerful steamer, whilst at the same time she will carry double the cargo of merchandize. With a fair wind, or at a few points on the beam, she will pass the steamer, and in the open sea will beat to windward with great effect, sailing two points nearer the wind, than with the sails alone, coming round very quickly, and losing nothing in the manœuvre; so that under these circumstances

she is nearly a match, under certain circumstances, for the powerful paddle-wheel steam-ships. This is a very important result for our merchant ships, and the system is making rapid progress.

Still there are difficulties to be overcome, from the screw being entirely under water, and having to run at great velocity, and from the action of the sea water upon the propeller and the machinery connected with it; but greater practical difficulties have been overcome, and they will be conquered, in this instance, by that union of practical skill with indomitable perseverance, which is the peculiar characteristic of the British engineer.

I fear that my remarks may have grown tedious, from thus dwelling so long upon a subject, not generally so interesting as to those who, like myself, have spent their lives in watching the course of these events; nor is perhaps a recital of them altogether suited to an address from this chair; but I trust you will pardon me if, in my anxiety to show the close connexion subsisting between the Mechanical and the Civil Engineer, as well as their mutual dependence upon each other, I may have dwelt too much at length, on that portion of the subject which possessed the greatest interest for me individually. My desire was to show, that exercise of the talents of one class, must lead to the employment of the skill of the other class—that they can and must mutually aid and assist each other—that they have but one common interest and bond of union; and they should look forward to the meetings of this Institution, as the arena, wherein they may excite each other to new enterprises, by which their country will be enriched, and their own names be handed down to posterity as the benefactors of mankind.

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.

RECEIVED BETWEEN JUNE 30, 1846, AND JUNE 29, 1847.

ORIGINAL COMMUNICATIONS.

Albano, B. No. 772. The state of the Bond Timbers at Covent Garden Theatre previous to the alterations in 1847. With one drawing, No. 4381.

Barlow, P. W. No. 764. Description of the Corrugated Cast-Iron Bridge on the Tunbridge Wells Branch Railway. With a model.

Beaumont, G. No. 754. The Advantages of the Railway Scale. With a specimen of the scale.

Braidwood, J. No. 767. On Fire-proof Buildings.

Conrad, F. W. No. 752. Description of the method adopted in preparing the foundations and in building the Bridge over the Poldervaart, on the line of the Amsterdam and Rotterdam Railway. Compiled from the original documents, by Charles Manby, Secretary Inst. C. E.

Elliott, J. No. 769. An account of the Sea Defences of Romney Marsh, commonly known by the name of Dymchurch Wall; the probable origin of the Marsh itself, and the manner in which it has been reclaimed from the sea. With three drawings, Nos. 4378 to 4380.

Fairbairn, W. No. 758. The Defects in the principle and construction of Fire-proof Buildings. With one drawing, No. 4359.

Froude, W. No. 765. The Law which governs the discharge of Elastic Fluids, under pressure, through short tubes and orifices. With diagrams.

Glynn, J. No. 757. A review of the Plans which have been proposed for connecting the Atlantic and Pacific Oceans, by a Navigable Canal. With plans.

Grantham, J. No. 761. Description of the "Sarah Sands," and other Steam Vessels, with direct Acting Engines and Screw Propellers. With four drawings, Nos. 4372 to 4375.

Heppel, J. M. No. 759. On the Expansive Action of Steam.

Henderson, Capt. A. No. 766. On the proportion of Steam Power for Ocean Navigation.

Highton, E. No. 770. Description of Highton's Safety Railway Chair. With one drawing, No. 4376, a model of the Chair, and specimens of the Key Wedges.

Jackson, G. B. W. No. 750. A description of the Great North Holland Canal, in three parts. Comprising,—

No. I. A description of the Great North Holland Canal.

No. II. On the Gaining of Land from the Sea, and the art of Building with Fascine Work, as generally adopted in Holland and Germany.

No. III. Description of the works executed in forming the Harbour and Works at Nieuwediep.

With seven drawings, Nos. 4351 to 4357.

Masters, Captain. No. 762. Remarks on the Iron Barque "Josephine" of Liverpool. With one drawing, No. 4377.

Murray, J. No. 760. Account of the progressive improvements in Sunderland Harbour and the River Wear. With eight drawings.

Rhodes, T. No. 756. Description of the improvements proposed to be executed in front of St. George's Pier Head, Liverpool. With two drawings, Nos. 4367 and 4368.

Richardson, J. No. 751. On the Ventilation of Mines. With one drawing, No. 4366.

Russell, J. S. No. 755. Remarks on the Practical Forms of Engineering Works, exposed to the action of the waves of the Sea, and on the advantages and disadvantages of certain Forms of construction, for Breakwaters and Sea Walls. With diagrams of the forms.

Whitworth, J. No. 771. On the Advantages and Economy of maintaining a High Degree of Cleanliness in roads and Streets, with an account of the Construction and Operation of the Street Sweeping Machine. With one drawing, No. 4382.

ORIGINAL DRAWINGS.

DONORS.

Albano, B. Elevation and Section of the Main Wall of Covent Garden Theatre, showing the position of the Rotten Bond Timber. No. 4381. Paper 774.

Edwards, G. View of Eccles Church, on the Norfolk Coast, partly buried in "Marram" hills, formed by the growth of the "Arundo arenarea," or "Ammophila arundinacea." No. 4358. Paper 750.

Elliott, J. Plan and Section of the Sea Defences of Romney Marsh, commonly known as "Dymchurch Wall." No. 4378 to 4380. Paper 769.

Fairbairn, S. Plan and Elevation of Messrs. Graig's Cotton Mill, at Manchester, previous to, and after the accident of March, 1847. No. 4359. Paper 758.

Grantham, J. Plans, Sections, Elevations, and Details of the "Diamond," "Emerald," "Antelope," "Sarah Sands," and other Steam Vessels, fitted up with auxiliary screw propellers. Nos. 4372 to 4375. Paper 761.

Highton, E. Elevation, Plan, and Sections of Highton's Safety Railway Chair and Key Wedge. No. 4376. Paper 772.

Jackson, G. B. W. General Plan of that part of North Holland extending from Amsterdam to the Helder, showing the course of the Great North Holland Canal.

Plans, Elevations, and Sections of the Dykes, the Willem, Buiksloop, Purmerender, and Zijp Locks, of the Floating Dry Docks, the Water Camels, &c. used on the Great North Holland Canal. Nos. 4351 to 4357. Paper 750.

Masters, Capt. Rigging draught of the Iron Barque "Josephine." No. 4377. Paper 762.

Newton, W., jun. Method of laying down the permanent way, on the Reading and Philadelphia Railway, U. S., and details of ditto. Nos. 4360, 4361. Paper 746.

Rhodes, T. Design for a Landing Pier proposed to be erected in front of George's Pier Head, Liverpool, for the accommodation of Steam Vessels and Ferry Boats. Nos. 4367-8. Paper 756.

Richardson, J. Plan of the different Methods of Ventilation employed in the Mines of Newcastle and South Wales. No. 4366. Paper 751.

Whitworth, J. Elevation and Plan of Whitworth's Street Sweeping Machine. No. 4382. Paper 771.

CATALOGUE OF PRESENTS.

BOOKS.

DONORS. TITLE OF BOOK.

Adcock, H. A Letter to the Mine Proprietors of Great Britain on Adcock's Spray Pump, by H. Adcock. Tract, 8vo. London, 1846.

Admiralty, The Lords Commissioners of, through Admiral Beaufort, Hon. M. Inst. C. E. Sailing Directions for the inner Route from Sidney to Torres Strait. Surveyed by Capt. P. King, R.N., Tract, 8vo. London, 1847.

Ashwell, J. Report of the Directors to the Shareholders of the Great Luxembourg Railway. Tract, 8vo. London, 1846.

Bushforth, F. A General Table for facilitating the calculation of Earthworks for Railways, Canals, &c., with a Table of proportionate parts. By F. Bushforth, M.A. 8vo. London, 1847.

Beaumont, G. D. B. On the selection of projected lines of Railway, with a description of the Railway Scale. By G. D. B. Beaumont. Tract, 8vo. London, 1846.

———————— The Law of Fire and Life Insurance, with the latest decisions, and an Appendix. By G. D. B. Beaumont. 8vo. London, 1847.

Bessemer, H. On the resistance of the Atmosphere to Railway Trains, and a means of lessening the same, together with an account of some improvements in Railway Carriage Axles. By H. Bessemer. Tract, 4to. London, 1847.

Braidwood, J. Report of W. Fairbairn, Esq., on the construction of Fire-proof Buildings. Tract, 8vo. Liverpool, 1844.

Brewin, C. Considerations on the probable Commerce and Revenue of the proposed Canal between Newcastle and Maryport. Anonymous. Tract, 8vo. London, 1802.

DONORS. TITLE OF BOOK.

Brewin, C. Report on a Line of Navigation from Newcastle-on-Tyne, to the Irish Channel. By H. Chapman. Tract, 8vo. London, 1795.

British Association for the Advancement of Science. The Report of the Association for the year 1846. 8vo. London, 1847.

Britton, J. Memoirs of the Life, Writings, and Character of Henry Hatcher. By John Britton. Tract, 8vo. London, 1847.

Buonaparte, H. R. H. Prince Napoleon Louis. Canal of Nicangua; or a project to connect the Atlantic and Pacific Oceans by means of a Navigable Canal. By N. L. B. Tract, 8vo. London, 1847.

Castle, H. J. Engineering Field Notes on Parish and Railway Surveying and Levelling. By H. J. Castle. Second Edition. 8vo. London, 1847.

——— Railway Curves. By J. H. Castle. Tract, 8vo. London, 1847. Plates and Diagrams.

Clark, Hyde. Contributions to Railway Statistics in 1845. Tract, 8vo. London, 1846.

——— On the Gauge Question, and on the performances of the Great Western "Leviathan" Locomotive. Tract, 8vo. London, 1846.

——— The Railway Herald, Vol 3, folio. London, 1846.

———, and Weale, J. The Railway Register, and Record of Engineering and Public Enterprise, for the year 1846. Edited by Hyde Clarke. 8vo. London, 1846.

——— The Statistics of Belgian Railway Traffic. By Hyde Clarke Tract, 8vo. London, 1846.

——— The Theory of Investment in Railway Companies, Tract, 8vo. London, 1846.

Clerk of Works Society. Report, with Cash Statement and Catalogue of Books in the Library, December, 1846. Tract, 8vo. London, 1847.

Colquhoun, E. P. Topography of the Harbour and position of the Long Walls of Athens. By Dr. H. N. Ulricht. Translated from the German, by E. P Colquhoun. 8vo. London, 1847.

DONORS. TITLE OF BOOK.

Curtis, Cockburn. Report on the Norwich and Yarmouth Navigation. By Cockburn Curtis. 4to. London, 1846. With a map.

——————— Reports of the Tidal Harbour Commissioners, 1845–46. 8vo. London, 1846.

Donaldson, T. L. Architectural Maxims and Theorems, in elucidation of some of the principles of Design and Construction, and a Lecture on the Education and Character of the Architect. By T. L. Donaldson. 8vo. London, 1847.

Dunkin, A. I. Report and Observations on the Proceedings of the British Archæological Association. Edited by A. I. Dunkin. Tract, 8vo. London, 1846.

Franklin Institute. The Journal of the Franklin Institute, of the State of Pennsylvania, and American Repertory of Mechanical and Physical Science. Third Series, Vol. 12. 8vo. Philadelphia, 1846.

Geological Society of Dublin. Journal of the Society, Vol. 3, Part 3. 8vo. Dublin, 1846.

Glasgow Philosophical Society. Statistical Account and Catalogue of the Society's Exhibition of Models and Works of Art. Tract, 8vo. Glasgow, 1847.

Haggard, W. D. Observations on the Standard of Value and the Circulating Medium of this Country. By W. D. Haggard. Tract, 8vo. London, 1847.

Hann, James. A Short Treatise on the Steam Engine, adapted for the use of Schools; in which is given practical rules for the use of Engineers. By James Hann. Part 1. Small 8vo. London, 1847.

Health of Towns Association. The Report of the Committee of the Health of Towns Association. Tract, 8vo. London, 1846.

Hill, W. An Essay on the Theory and Practice of setting out Railway Curves. By W. Hill. Tract, 8vo. London, 1847.

Holtzapffel, C. The Engineer and Machinist's Assistant. By D. Scott. Parts 19 to the end. Folio. Glasgow, 1846–47.

——————— Turning and Mechanical Manipulation. By C. Holtzapffel. Vol. 2, containing the action of Cutting Tools. 8vo. London, 1846.

DONORS. TITLE OF BOOK.

Hübbe, M. Kurzgefaste Geschichte und Beschreibung der Wasserbauwerke im ninte Kikebuttell. 8vo. Hamburgh, 1844.

Hughes, J. Concise Tables for the Calculation of Earthwork. By J. Hughes. Tract, 12mo. London, 1846.

Hume, Rev. A. The Learned Societies and Printing Clubs of the United Kingdom. By the Rev. A. Hume. 8vo. London, 1847.

Ibbetson, D. J. H. Practical Rules for ascertaining the relations between Alternations in Gradients, and the corresponding changes in the contents of Earthwork. By D. J. H. Ibbetson. Tract, 8vo. London, 1847.

Instituto Lombardo di Scienzi, Lettere ed Arti. } Elogio di Bonaventura Cavalieri, recitato all' occasione del sesto Congresso Scientifico Italiano dell' I. R. Instituto Lombardo di Scienzi, Lettere, ed Arti, da Gabrio Piola, Presidente delle stisso, I. R. Instituto, &c. 4to. Milan, 1844.

——————— { Giornale dell' I. R. Instituto Lombardo di Scienzi, Lettere, ed Arti. Vol. 5. 4to. Milan, 1845.

——————— { Memorie dell' I. R. Instituto Lombardo di Scienzi, Littere, ed Arti. Vol. 2. 4to. Milan, 1845.

Jobard, M. Chemin de fer Electro-pneumatique, proposé par M. Jobard, Directeur du Musée de l'Industrie. Tract, 8vo. Brussels, 1846.

Literary and Philosophical Society of Manchester. } Memoirs of the Society. Second series, Vol. 3. Part 2. 8vo. London, 1846.

London Institution, The. On the correlation of Physical Forces, By W. R. Grove. 8vo. London, 1846.

Lowe, G. The Cyclopædia, or Universal Dictionary of Arts, Sciences, and Literature. Edited by Dr. Abraham Rees. 45 vols. 4to. Plates. London, 1820.

Mallet, R. Address delivered at the Anniversary Meeting of the Geological Society of Dublin. By R. Mallet. Tract, 8vo. Dublin.

DONORS. TITLE OF BOOK.

Manby, C. (Secretary.) Bibliotheca Britannica, or a General Index to the Literature of Great Britain and Ireland, ancient and modern, including such foreign books as have been translated into English, or printed in the British dominions; also a copious selection from the writings of the most distinguished authors of all ages and nations. By Dr R. Watt. 11 vols. 4to. Edinburgh, 1824.

———— On the Ventilation of Mines; especially in the thick, or ten-yard Coal Mines of South Staffordshire. By B. Gibbons. 8vo. Birmingham, 1847.

May, C. A Catalogue of Messrs. Ransome and May's Implements and Machines. Tract, 8vo. London, 1846.

Murray, J. An Abstract of a Report relating to the Improvement of the River Wear, and the Port of Sunderland. By C. Labelye. Tract, small 4to. Newcastle-on-Tyne, 1748.

———— Reports to the Honourable Commissioners of the River Wear, on the State of the River, Harbour, Piers, &c., &c., of the Port of Sunderland. By R. Dodd. Tract, small 4to. Sunderland, 1794.

———— The Report of John Smeaton, Engineer, on Mr. James Shout's plan for Re-building and Extending the old Pier of the Harbour of Sunderland. Small 4to. Gateshead, 1780.

———— The Report of Sir John Rennie to Sir C. Sharp, Chairman, and to the other Commissioners of Sunderland Harbour. Tract, folio. London, 1831.

Pease, W. The Guide to Surveying and Levelling. By W. Pease. Tract, 12mo. London, 1846.

Pickett, W. V. The Fine Arts Journal; containing the Exposition of a new system of Architecture. 4to. London, 1847.

Price, H. C. Remarks on the Ventilation and Warming of Prisons and other Public Buildings. Anonymous. Tract, 8vo. London, 1844.

Redman, J. B. Proposal for re-establishing the British Southern Whale Fishery, through the medium of a Chartered Company. By C. Enderby. Tract, 8vo. London, 1846.

DONORS. TITLE OF BOOK.

Rennie, Sir John (President.) A History of Inventions, Discoveries, and Origins. By John Beckmann. Translated from the German, by W. Johnston. Fourth edition, revised and enlarged by Mrs. Francis and Griffith. 2 vols. 8vo. London, 1846.

——————— Observations on the Report of Captain Evans, R. N., upon the Harbours of Lorne, Loch Ryan, Port Patrick, Donaghadee, and Belfast. By Sir John Rennie. Tract, 8vo. London, 1846.

——————— Introduction à la Mécanique Industrielle, Physique ou Experimentile. Par J. V. Poncelet. Seconde édition. 8vo. Metz, 1841.

——————— Traité de Méchanique. Par S. D. Poisson. Seconde édition. 2 vols. 8vo. Paris, 1833.

Richardson, J. Observations on the Ventilation of Mines, with a description of a new Mine Ventilator. By W. P. Struvé. Tract, 8vo. London, 1846.

Royal Agricultural Society of England. The Journal of the Society. Vol. 8. Part 1. 8vo. London, 1846.

Royal Cornwall Polytechnic Society. List of the Society's Premiums and Prizes for 1838. Tract, 8vo. Falmouth, 1838.

——————————— The Fourteenth Annual Report of the Society. Tract, 8vo. Falmouth, 1846.

Royal Irish Academy. Proceedings of the Royal Irish Academy. Vol. 3. Parts 1 and 2. 8vo. Dublin, 1847.

——————— Transactions of the Royal Irish Academy. Vol. 21. Part 1. 4to. Dublin, 1847.

Royal Society of Edinburgh. Proceedings of the Royal Society of Edinburgh. Vol. 2. Nos. 27 and 28. 8vo. Edinburgh, 1846.

——————————— Transactions of the Royal Society of Edinburgh. Vol. 16. Part 2. 4to. Edinburgh, 1846.

Sibley, C. R. Tables for estimating the contents, in Cubic Yards, of the Earthworks of Railways, and other Public Works. By C. R. Sibley and W. Rutherford. 4to. London, 1847.

Smith, T. M. A Memoir of the Pont-y-tu-prydd over the River Tâfe, in Glamorganshire. By T. M. Smith. 4to. Plates. London, 1847.

DONORS. TITLE OF BOOK.

Smith, T. M. Reports on the Iron Works, Manufacturing Establishments, and Mineral Property at Couvin, in the district of the Sambre and Meuse, Belgium. By Thomas Sopwith and Thomas M. Smith. 8vo. London, 1846.

Solly, Professor E. Abstract of a Lecture on the application of Electricity to practical purposes. By Professor E. Solly. Tract, 8vo. London, 1847.

Spence, W. A Treatise on the Principles relating to the Specification of a Patent Invention. By W. Spence. 8vo. London, 1847.

———— Copyright of Designs, as distinguished from Patentable Inventions. By W. Spence. Tract, 8vo. London, 1847.

Statistical Society of London. The Journal of the Society. Volume 9. Parts 3 and 4. 8vo. London, 1846.

Stevenson, D. Report in reference to the Harbour of Peterhead. By D. Stevenson. Folio. With folding Map of Peterhead Harbour.

Tate, T. Exercises in Mechanics and Natural Philosophy. By Thomas Tate. Second Edition. 12mo. London, 1847.

Turner, T. Remarks on the Right of Property in Mechanical Invention, with reference to Registered Designs. By T. Turner. Tract, 8vo. London, 1847.

Vignoles, C. jun. Vignole's Steam Railway. By Charles Vignoles, jun. Tract, 8vo. Bradford, 1846.

Vulliamy, B. L. Complément d'études pratiques sur la Navigation interieur eet rapprochements entre Canaux et Chemins de Fer, Français, Anglais, et Belges. Par François Aulagnier. 4to. Paris, 1842.

Weale, J. The High-pressure Steam Engine investigated. An exposition of its comparative merits, and an Essay towards an improved system of construction. By Dr. E. Alban. Translated from the German by W. Pole, Assoc. Inst. C.E. 8vo. London, 1847.

Webster, T. The Principles of Hydrostatics, an elementary Treatise on the laws of Fluids, by T. Webster. Third Edition. 8vo. London, 1847.

White, G. F. An Encyclopædia of Civil Engineering, Historical, Theoretical, and Practical. By Edward Cresy. 8vo. London, 1847.

DONORS. TITLE OF BOOK.

Wicksteed, T. Report to the Directors of the East London Waterworks, being the replies to a series of questions proposed by Dr. Southwood Smith, relative to the practicability and expediency of giving a constant supply. With an Appendix. By T. Wicksteed. 4to. London, 1847.

Young, R. Dictionnaire de l'Academie Française. Sixième édition. 2 vols. 4to. Paris, 1836.

——— A course of Lectures on Natural Philosophy and the Mechanical Arts. By Dr. T. Young. 2 vols., 8vo. London, 1845.

CHARTS AND MAPS.

Admiralty, The Lords Commissioners of, through Admiral Beaufort, Hon. M. Inst. C. E. — The Charts published by the Admiralty, between the 1st of June, 1846, and the 1st of June, 1847.

Ditto, between the 1st June, 1847, and 7th February, 1848.

PRINTS AND ENGRAVINGS.

Conrad, Le Chevalier. Plans, Elevations, and Sections of the works constructed for the purpose of building the foundation for the bridge over the Poldewaart, on the line of the Amsterdam and Rotterdam Railway. Nos. 4370 and 4371. Paper 752.

Elliot, J. Plan of Romney Marsh, Walland Marsh, Denge Marsh, and Guilford Marsh, taken in the year 1617. No. 4378. Paper 769.

Motley, T. Engraving of the proposed Iron Bridge over the Thames at Lambeth Palace.

Rennie, G. Plan and Elevation of the Bridge over the River Meuse, at Val St. Lambert, on the line of the Namur and Liège Railway. No. 4369.

Roffway, J. Portrait of Sir Marc Isambard Brunel. Engraved by J. Carter from the original painting by S. Drummond, A.R.A.

Vulliamy, B. L. Drawings of the Clock for the New Palace at Westminster.

Weale, Jno. Twenty-five Engravings, Folio, of the Great Britain Steam Ship.

MODELS.

DONORS.

Bidder, S. P. Machine for loading Vessels with coals from a Railway Wharf.

SPECIMENS.

Albano, B. Specimen of Decayed Bond Timber from the main walls of Covent Garden Theatre, during the execution of the repairs and alterations in 1847.

Lambert, W. Specimens of Lambert's Patent Vulcanised India Rubber Diaphragm Cock Valves.

Paul and Franks, Messrs. Specimen of a Gas Burner, called the National Economic Gas Burner.

Wilkie, G. Specimen of Galvanised Tinned Iron. Morewood and Rogers' Patent.

MISCELLANEOUS.

Haggard, W. D. A Double Protractor for describing Angles and Measuring Distances at the same time, invented by W. D. Haggard.

Jessop, W. Portrait of the late W. Jessop, C.E., presented by his son, Mr. W. Jessop, through Mr. A. Burges, M. Inst. C.E.

Mallet, R. Standard Bar of Wrought Iron.

Murphy, J. Bust of the Rt. Hon. W. J. Huskisson, M.P., &c.

Rennie, G. Portrait of the late Joseph Whidby, C.E.

Sherrard and Hall. A Pentagraph.

Stephenson, R., M.P., *V. P.* Bust of George Stephenson, Esq., modelled by Mr. Christopher Moore.

Vulliamy, B. L. The Works of a Clock made by Tompion about the year 1670, and presented by King Charles II. to Barbara Villiers, Duchess of Cleveland.

OFFICERS—1848

COUNCIL.

PRESIDENT.

JOSHUA FIELD, F.R.S.

VICE-PRESIDENTS.

WILLIAM CUBITT, F.R.S.
JAMES M. RENDEL, F.R.S.
JAMES SIMPSON, F.G.S.
ROBERT STEPHENSON, M.P.

MEMBERS.

JOHN F. BATEMAN.
GEORGE P. BIDDER.
ISAMBARD K. BRUNEL, F.R.S.
JOSEPH CUBITT.
JOSEPH LOCKE, M.P., F.R.S.
CHARLES MAY.
JOHN R. M'CLEAN.
JOSEPH MILLER, F.R.S.
WILLIAM C. MYLNE, F.R.S.
THOMAS SOPWITH, F.R.S.

ASSOCIATES.

JOHN CLUTTON.
THOMAS HENRY WYATT.

AUDITORS.

WILLIAM NEWTON.
JOHN WRIGHT.

TREASURER.

EDWARD MARJORIBANKS.

SECRETARY.

CHARLES MANBY, F.G.S.

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1848.

January 11, 1848.

SIR JOHN RENNIE, President, in the Chair.

No. 774.—"On the Manufacture of Artificial Stone, with a Silica base."*—By Frederick Ransome, Assoc. Inst. C.E.

The following process for making artificial stone was arrived at by the Author, whilst making experiments, for the purpose of finding a combining material, by which particles of matter (such as stone, marble, &c.) could be united, to form a mass more uniformly equal in its texture, than the productions of nature.

It occurred to him, that could flint, or silica, be brought into a semi-fluid state, and be used as the medium, the desired object would be effected, and the artificial compound would possess the appearance and all the useful properties of natural stone.

Now as silica (flint, &c.) is an acid, it will form compounds with metallic oxides (earths, alkalies, &c.) Most of these, however, are solid, and are only fusible at very high temperatures; but certain combinations can be formed with the alkalies, which remain fluid, and these are used as the combining medium.

The process is very simple.—Broken flint is subjected to the action of caustic alkali (soda or potash) in a boiler, at a high temperature, under pressure, and it is found, that the alkali will dissolve a large proportion of silica, and will lose its causticity; the solution, thus obtained, can be evaporated to any required degree of consistency.

* The discussion on this Paper extended over three evenings; but an abstract of the whole is given consecutively.

It is generally employed at the specific gravity of 1·600 (water being 1·000); and this solution (soda being used as the alkali) is found to possess the following composition in 100 parts:—

Silica	20·43
Soda	27·05
Water	52·52
	100·00

When properly made, it is perfectly transparent, possesses great tenacity, and, on the addition of a strong acid, becomes a solid mass by the precipitation of the silica.

When worked up with clean raw materials, such as sand, clay, portions of granite, marble, &c., together with a small portion of powdered flint, the compound possesses a putty-like consistence, which can be moulded into any required form, and is capable of receiving very sharp and delicate impressions.

When taken from the mould, it should be allowed to dry very slowly, and afterwards be submitted, in a kiln, to a gradually increased temperature, up to a red heat, which is maintained for some time.

The changes which take place during this operation are as follows:—

The water is entirely driven off, the silicate of soda is altered in its composition, and another silicate, insoluble in water, is produced, by part of the soda combining with an additional portion of silex, at the high temperature to which it is submitted, and thus the whole becomes a mass, harder in texture and less porous than natural stone; indestructible by atmospheric changes, cold, moisture, or even by boiling water.

It is easy to perceive to what numerous purposes the products of the system are applicable. To all varieties of architectural ornaments and decorations, as columns, capitals, balustrades, mouldings, cornices, chimney-pieces, &c.; for which the finer descriptions of sands and clays are employed; as well as for floorings, steps, pavements, of any design and colour, as they can be produced of any tint, and even be inlaid with colours, by the addition of various metallic preparations.

By using coarser descriptions of sand, grits, &c., grinding-stones of all kinds can be formed.

The chief peculiarity which distinguishes this from other artificial stones, which have been brought under the notice of the

public, consists in the employment of silica, both as the base and as the combining material, whereby the compound approaches in its nature and composition to the best kinds of natural stone. Now most of the other varieties of artificial stone, hitherto produced, are compounds, of which lime, or its carbonate, or sulphate, forms the base; and in some instances they consist, in part, of organic matters, in combination with inorganic matters as the base. Such varieties, although very extensively and usefully employed in internal and ornamental decoration, have been found to be far inferior in strength and durability to the productions of nature, and are, consequently, seldom, or never employed, where either of those qualities are required.

Experiments which have been made upon the strength of the artificial stone, prepared as previously described, have shown, that it is superior to many of the natural stones, generally used in buildings; and almost any amount of hardness can be given to it, by increasing the quantity of silicate, and subjecting it to a greater degree of heat.

For the purpose of proving its durability, specimens have been exposed to the weather for upwards of two years, without having suffered the slightest injury, although water has frequently been frozen in and upon them. They have also been submitted to the long-continued action of hot and cold water, and even to that of acid solutions, without being perceptibly affected.

From the foregoing remarks, it will be obvious, that this substance is applicable to all branches of constructive, or decorative architecture; in fact it is difficult to define the limit of its applicability, or to predict to what amount of usefulness it may not be extended.

Mr. F. Ransome recapitulated the principal points of the description of the process, as given in the paper, and added, that the pieces of broken flint were suspended in wire baskets within the boilers, filled with a strong solution of caustic alkali, and then subjected to a temperature of 300° Fahrenheit, under a pressure of from 50 lbs. to 80 lbs. per square inch; the caustic alkali was thus enabled to attack the flint, which entered into solution with it, whilst the earthy and foreign particles were precipitated, and were left in the bottom of the vessel, when the solution was drawn off. The water was then evaporated, to as great an extent as was judged necessary, and to the alkaline liquid was added the sand, a small quantity of pipe-clay, and some powdered flint; the latter was for

the purpose of taking up any excess of alkali, which would be prejudicial. The whole was then worked in a pug-mill for about twenty minutes, till it became a kind of granulated, but very tenacious, substance, of the consistence of putty, which was squeezed into moulds, from which it retained the sharpest impressions. These casts were then placed in a potter's kiln, the temperature of which was raised very gradually for the first twenty-four hours; the intensity of the fire was then augmented, until at the end of forty-eight hours a bright red heat was attained and the kiln was then allowed to cool gradually, which occupied about four, or five days.

A chemical effect was evidently produced in the kiln, by the alkali combining with the free silex and forming a kind of glass; indeed the substance of the artificial stone appeared to be simply sand, aggregated and held together mechanically, by the tenacious quality of the fused silicate of soda, which was intimately combined with the particles.

In reply to questions from Dr. Faraday and Mr. R. Stephenson, M.P., Mr. F. Ransome explained, that 1 pint of the alkaline solution, at the specific gravity of 1·6, sufficed for 10 or 15 pints of sand and other materials. The general proportions might be stated to be—

10 pints of sand.
1 „ of powdered flint.
1 „ of clay.
1 „ of alkaline solution.

The amount of dry silicate of soda, in an average specimen, would be about 5 per cent.

In some of the early trials, the sand used was merely the scrapings from the flint roads, and some of the specimens exhibited were composed of that material.

The strength of the artificial stone, for resisting impact and pressure, had been ascertained under a powerful hydraulic press, to be very considerable.

Dr. Faraday said he had examined this substance so superficially, that he felt a difficulty in expressing any opinion upon it, and, in fact, he had come to the meeting rather to learn the particulars of an invention, which (if correct), must be an important introduction, than to discuss its merits. He would suggest, that some specimens should be exposed to the action of the atmosphere in London, where, in consequence of the air and the rain being loaded with sulphurous acid, from the vapour of coal in combustion, almost every kind of building-stone was more, or less, acted upon. This

substance appeared to be a collection of particles of sandstone grit, intimately combined with the silicate of soda, by whose tenacious properties, when fused, they were held together, as by a kind of glass, enveloping the particles. It was essential to keep this in mind, in arguing on the properties of the substance, and it would be very desirable to ascertain the effect of boiling it in water for a length of time, and then of exposure to frost and other changes of temperature: as, from its texture, it would appear to be susceptible of imbibing moisture, or, like sandstones, of forming a filter.

He had observed, that when some kinds of flint-glass were boiled, a portion of the alkali was acted upon and dissolved; but a coat of insoluble silicate was left on the surface of the glass, which was thus protected from further injury. It would remain to be proved, whether the silicate, when so divided among minute particles as in the artificial stone, would have the same effect as when extended over a surface, as in the flint-glass; still he thought this material must be considered as a sort of glass, partially fused. It was evidently a very strong, and apparently durable substance, and would he conceived be useful for many purposes.

Mr. PELLATT said he had hitherto had no opportunity of examining the substance carefully; but, from the description in the paper, he was induced to believe, that part of the process of manufacture somewhat resembled that of the Stourbridge clay melting-pots, which it was an object of such importance, in the manufacture of glass, to obtain as perfect as possible. With respect to the exudation of the alkali, or its solubility in glass; it had been imagined, that when the alkali and silica were properly proportioned, and completely amalgamated and fused, they would become so intimately combined that nothing could separate them. But from investigations he had made on the specific gravity of various kinds of glass, and more particularly from some pieces of Roman glass recently dug up in the city, he was induced to believe, that the alkali did exude. In these latter specimens the surface was dim and rough, whilst the recent fractures were bright and clear, evidently showing that the alkali had been acted upon. In general he had observed, in ancient glass, that when it was coloured with metallic oxides the surface was seldom injured.

Dr. FARADAY explained, that the presence of uncombined alkali could always be detected, by pounding glass in a mortar, moistening it with water, and then testing it with turmeric paper.

Mr. C. H. SMITH said, it appeared from the paper, that the method of preparation of the artificial stone somewhat resembled that

of terra-cotta; but that the materials employed were different. He thought the apparent porosity which had been mentioned was not likely to be an objection, as some very porous natural stones were exceedingly durable; for instance, the Craigleith and the Alstone-moor stones were both porous, and good stock bricks also were very absorbent of water, and yet few substances were more durable. He apprehended, however, that the greatest objection to the material under consideration would arise from its warping and shrinking, in the process of baking. This had been found the case with all the terra-cotta ornaments that had been attempted to be introduced, and it had been impossible to keep architectural ornaments in a straight line, or to get them to contract equally throughout the mass. An attempt had been made to introduce terra-cotta ornaments at St. Pancras Church and St. Michael's Church; but the irregularities of form, arising from contraction, were so great, that the effect was inferior to cut stone, and, from the quantity that proved useless, the ultimate expense was greater than stone. If any line of these ornaments was examined, it would be found, that the major part was cracked, and the shadow detected the irregularity of the surface. In putting up the capitals round the columns, as they were necessarily made in several pieces, none of which contracted equally, they scarcely ever fitted well round the shafts. They were also liable to give way after a certain degree of exposure, as occurred with the ornaments of the spire of St. Michael's Church, which fell and did considerable damage. Indeed, the gradual decline and extinction of all the terra-cotta manufactories, showed, that there were either great difficulties in the production, or that the manufacture was not profitable. He was inclined to think, that unless there was a large demand, so as to enable considerable quantities to be made, and to be baked together regularly, it could not be profitably manufactured. The burning demanded extraordinary care, as the slightest want of attention on the part of the fireman sufficed to fuse all the pieces together, and the whole kilnfull was destroyed. He had seen this occur. If a piece of terra-cotta exceeded 1½ inch or 2 inches in thickness it was seldom thoroughly baked, and in attempting to keep it a little longer time in the kiln it was either cracked, or fused.

From his own experience he was convinced, that stone could be carved accurately, at a less cost than imperfect terra-cotta ornaments could be manufactured. He was not sufficiently acquainted with the process of making this artificial stone, to draw a comparison between it and terra-cotta, and, as the component parts differed, it might not possess the same defects: but he thought, that

it should be subjected to the test of time, before it was asserted that it would supersede carved stone.

Mr. PELLATT confirmed the difficulty of making large articles of terra-cotta. He judged from the manufacture of articles of Stourbridge clay; still that was accomplished. There was an establishment at Battersea, where large vessels of clay were perfectly made and burned. In Staffordshire both large and small wares were stoved with certainty, although even there accidents did occur, in spite of the greatest attention.

Mr. R. STEPHENSON, M.P., *V.P.*, observed, that whether from a bad model, an imperfect mould, or the contraction of the substance, the large specimen (a tazza vase) was very inaccurate in its outline; and he should be inclined to doubt this invention ever superseding carved stone, even for architectural ornaments, and much less for works of art. Still he would not go so far as to condemn the artificial stone until it had been tested by time. He thought, however, from what he had yet seen, that it must be materially improved, before it would rival the artistic productions of Mr. Thomas, for Mr. Barry, at the New Houses of Parliament.

Professor DONALDSON accorded with the previous speakers, in fearing that the cost of the artificial stone would interfere with its general use; but that was a question which could be better answered by the manufacturers. The component parts appeared to be good, and calculated to produce a very durable compound, and he did not think the apparent porousness was objectionable. The Travertine stone was remarkably porous; but was, at the same time, extremely durable, and was not at all injured by moisture, or frost.

Mr. FAREY said, the substances under consideration were so very unlike in composition, that it was not fair to argue upon the properties of the artificial stone, from the failure of the terra-cotta, which was notoriously badly manufactured; indeed he believed, that with the exception of the pieces that had been used as specimens, there never had been any good ones produced. The silicate of soda, which was only used as a cement, for agglomerating the particles of the very durable substances of which the mass was composed, was, in his opinion, the best substance that could have been selected, and on that account also, he was inclined to believe the amount of contraction would not be sufficient to be prejudicial. It was, in fact, somewhat like Prosser's system of producing porcelain ornaments, by subjecting dry powdered clay to great pressure and then baking them. In that process, as there was no moisture to be evaporated, there was no contraction, and the articles, after baking, appeared to fill the moulds completely. He would suggest Mr. F. Ransome's submitting some of the silicate mixture to that process.

The composition of the artificial stone ought to resemble that of the masses from the Geysers of Iceland, where the water held silica in solution, which was deposited upon any object over which the water passed, for any length of time.

Mr. F. RANSOME said, the remarks that had been made upon the artificial stone, and the comparison of it with terra-cotta, confirmed his opinion of its merits. The substances could not be compared, either for purity, or for durability, and the mode of preparation was as different as the effects upon them, when submitted to heat, during the manufacture, or to cold and moisture afterwards.

The materials for forming the artificial stone were worked up almost in a dry, or crumbling state, and it was only the inherent adhesive properties of the silicate of soda, that held the particles together, and preserved the delicate edges, until the mass was baked and the silicate was fused. Some of the specimens certainly appeared porous, but others were very compact. This arose from the different sizes of the particles of sand of which the masses were composed. He could not allow, that pieces could not be produced, with a regular and correct outline, as he had made slabs for chimney-pieces, 7 feet long, by 9 inches, or 12 inches wide, and 3 inches thick, which, after being baked, were perfectly true. The vase which had been remarked upon, was made from an indifferent model, and had been badly moulded; in fact it had only been produced to show the substance, after being baked in a considerable mass. He submitted, that the composition of the artificial stone should alone be considered, as every difficulty of mechanical manipulation might be presumed to be capable of being overcome.

Dr. FARADAY was of opinion, that this question, like everything which was brought before a Society, so eminently practical as the Institution of Civil Engineers, should be treated in its simplest form. Without, therefore, entering into the chemical properties of silica in combination with caustic alkali, it sufficed to notice the great difference between the composition and the manipulation of the terra-cotta and this artificial stone. The former consisted of clay, mingled with a considerable quantity of water, which would, of course, contract in burning, not only from the natural tendency of the material; but from the mere evaporation of the water; whereas the latter was composed of a number of particles of sand, worked almost in a dry state, and cemented together by a small quantity of silicate of soda, which had not any great tendency to contract, even in fusing, and the heat to which the mass was exposed, was not sufficient to cause any change of bulk in the particles of sand. This was, he imagined, sufficient to show, that the apprehensions of a great extent of contraction was groundless, and there

was no reason why great regularity of outline should not be retained, provided the pieces were well and carefully worked and stoved.

Mr. PELLATT said, that the advantage of using such substances as would not contract considerably in the kiln, was so well understood by makers of glass-house pots, that they introduced as large a quantity as possible of old pots, ground up and intimately mingled with the fresh clay.

Mr. R. T. RANSOME said, the specimens on the table were not produced as perfect, because there had not, as yet, been scarcely sufficient time for perfecting the manufacture; but he must contend, that good progress had been already made, and he thought enough had been said, by the eminent chemists and practical men, who had spoken,to show that the subject deserved attention. He was convinced, that if good models were selected, and care was taken in the manipulation, architectural ornaments, and other works of art for external decoration, could be produced, with a precision of outline and a delicacy which would scarcely be surpassed by carved stone.

Mr. F. RANSOME begged to draw attention more particularly to the larger specimens, which showed, that a correct outline was perfectly compatible with a considerable mass of the material; and he thought there was no evidence of such an amount of contraction in baking, as would interpose much difficulty in the production of any forms.

With respect to the porosity of the substance, it was evident, that must depend upon the size of the particles of sand used in the preparation. Some of the specimens were as compact in appearance, and of as great specific gravity, as granite.

Dr. GARROD said he had examined Mr. Ransome's process with great care, and had been somewhat surprised at the results of some of his experiments; these he attributed to the quality of the silica base, which gave the substance an amount of strength and durability not at all possessed by the terra cotta, with which (erroneously, in his opinion) it had been compared.

The chemical nature of the artificial stone had been so well described, that it was useless to recur to it, beyond observing, that an almost indestructible cement was used for the aggregation of the particles, by the combination of the silica and the alkali, and, that if properly proportioned, an insoluble glass would be formed, in the process of baking, which would not only hold the mass together very firmly; but by enveloping each particle composing it, would afford protection against injury from any fluid, or the

air, traversing the cellular structure, between the particles; the cells must, moreover, be very minute, as the material, on leaving the pug-mill, was subjected to a certain amount of pressure in being squeezed into the moulds.

Among other trials to which the artificial stone had been subjected, a piece weighing, when dry, 347 grains, was immersed in hot water during 160 hours; for 60 hours of which the temperature was kept up to the boiling point; it was then taken out, dried, and weighed, and was found not to have lost any of its weight, nor could the slightest trace of alkali be discovered in the water that had been used. This experiment was, he thought, conclusive as to the probable effects of moisture and of the atmosphere.

Vases and other vessels formed from the artificial stone had been filled with water, which had been allowed to freeze in them, without producing any injurious effects, either by bursting the vessels, or by chipping portions from the surface, as so frequently occurred with carved natural stone.

Mr. BARRY had not yet had an opportunity of testing the qualities of this artificial stone; but from the appearance of the specimens, the apparent solidity of the texture, the insolubility of the silica base, and the opinions that had been expressed upon it, he should feel it his duty to make a trial of it, and should be happy to communicate to the Institution the results of his experiments.

The Rev. the DEAN of WESTMINSTER had recently seen the process of manufacturing this artificial stone; and as far as a very rapid inspection enabled him to form an opinion, he felt great confidence in the result, when more experience, in the mode of manipulation, enabled Mr. Ransome to combat the difficulties inherent in the introduction of any new substance.

All geologists were conversant with the experiments of Humphry Watt and Sir John Hall. The results were somewhat analogous to the produce of Mr. Ransome's process. Red sand, when boiled for a considerable time with sea water, and subjected to pressure, had formed a substance very like the artificial stone under discussion. It was peculiar, that there was no great excess of salt observable in the specimens produced by Sir John Hall's process, and they were nearly as hard as natural red sandstone. The experiments in submitting pounded chalk to heat under pressure, and changing it into crystalline marble, and converting pounded basalt, under the same process, into greenstone, were particularly interesting.

His confidence in the durability of this artificial stone was increased, by observing how evidently the process of its production was based upon the operations of Nature, in the formation of rocks.

The sand, which was found in the Isle of Wight, on Bagshot Heath, at Woolwich, at Ipswich, and in so many other places, was known to have been produced by trituration, and by disintegration of certain rocks, from exposure to the action of the air, and however loose the particles were on the surface, they became indurated, and formed compact rocks lower down, as they were subjected to pressure and approached that which was now acknowledged to be central heat.

The hardest quartz pebbles, when examined under a powerful lens, exhibited an aggregation of particles such as he had described.

The quartz rock at the Lickey Hill, near Bromsgrove, at Hart Hill, near Nuneaton, and in other parts, further illustrated his position. This rock, from its enduring qualities, was extensively used upon all the roads where it could be procured, and portions of it, broken up by some great convulsion, at an indefinite period, and rounded by friction, formed the hard pebbles of the gravel which was so general throughout the country.

He thought the process, under discussion, was of considerable importance in every point of view, and merited the best attention of the engineer and the architect.

Sir H. De la Beche could add very little to what had been observed with respect to the process. It was clear, that the substance produced greatly resembled a compact sandstone, and its durability would be exactly in proportion to the hardness of the aggregated particles and the resisting quality of the cementing medium, presuming it to be intimately mixed and in due proportion. Now, as a silicious cement was the most enduring, and the action of nature had been evidently taken as the model for the process, there was no reason why the result should not be the production of a substance, very nearly indestructible, from any ordinary action to which natural stone would be subjected, with this advantage, that in its plastic state the artificial stone could be easily moulded to various forms, which could only be given to natural stone by the expensive process of carving. This adaptation of chemical knowledge to mechanical art was deserving of all praise, and he was of opinion the process was a great desideratum.

Mr. Walker was much pleased with the external appearance of the artificial stone, and of the texture of the fractured substance. It was to be regretted, that when Dr. Garrod was trying the experiments as to the solubility of the cementing medium, he did not ascertain to what degree the mass would absorb moisture. Some of the specimens were stated to possess a specific gravity equal to granite. Now if, at the same time, it was equally non-absorbent,

there could be no doubt of the value of the production; nevertheless, all its intrinsic merits were comparative useless, unless the price was so low as to enable it to compete with natural stone. That was a question of great importance, more particularly for engineering works. It appeared from inquiries he had made from Mr. F. Ransome, that the price of the artificial stone would not much exceed that of Bramley Fall stone. Now, if dressed blocks could be produced at three shillings per cubic foot, if anything beyond a perfectly plain face was required, it was evident this material would be cheaper than natural stone. A knowledge of the dimensions of the blocks that could be produced, was also important for engineering purposes.

Mr. R. PHILLIPS said he had also made some experiments upon the chemical nature of the artificial stone, and suspecting that a portion of the alkali might be uncombined, he reduced a piece of the substance to powder, expecting that, as with glass, on moistening the powder, and using test paper, he should have detected the presence of the alkali; such, however, was not the case, and it was evident, that the alkali was more perfectly combined than in glass. He went farther, and tried the powdered substance in heated acid; but without producing anything like the decomposition of it. He was therefore of opinion, that any substance, in which the silica and alkali were so intimately combined, would require the action of ages upon it, to produce any apparent decomposition, or alteration of form.

Mr. RENDEL, *V. P.*, acknowledged the importance, to engineers, of ascertaining the cost of the material; yet it was of equal importance to ascertain the dimensions of the masses that could be produced, as, in the course of an engineer's practice, there occurred many cases, where it became necessary to place considerable masses of material, in a short space of time, and others wherein single masses of large dimensions were indispensable. He would suggest, whether it would not be practicable to produce hollow vessels of considerable size, of this apparently indestructible material, and to fill them with less expensive concrete. If this could be accomplished, he thought the material might be extensively used for engineering purposes. It was of great importance to have the materials of certain sizes and ready prepared, as it enabled so much more work to be done in a given time. It was on this account, that brick-work was so convenient; but he suggested the employment of the artificial stone, if it could be procured in good masses, for situations where cofferdams were not practicable, and where the diving-bell must be used.

Mr. F. RANSOME stated in reply, that up to the present period, his

experience in manufacturing large masses was not great; as he had hitherto made nothing larger than 2 feet, or 2 feet 6 inches cube. He thought, however, that the only limits to the production of masses would be the machinery required, their capability of bearing removal to the kiln, and the time required for baking them thoroughly.

In answer to a question from Mr. T. H. Wyatt, Mr. Ransome said, the power of the artificial stone to resist pressure, had been tried comparatively with Caen, Bath, Portland, and York stone, and it had proved superior to all of them. He was not prepared to state its power of resistance per cubic inch, but would ascertain that point.

Mr. WALKER agreed in the desirableness of ascertaining the largest dimensions that could be produced. In ordinary work, the principal objection to the use of small stones, was the amount of labour in dressing the surface, and the consequent cost. This material, being moulded, overcame the objection to small masses, and as it was well known, that bricks made the soundest work, under certain circumstances, with this material, the same amount of soundness might be obtained, with apparent indestructibility from decay. It did not, however, appear to have been ascertained whether the artificial stone was capable of being united by common mortar, or cement. It was desirable to verify this point.

Dr. GARROD stated, in reply to questions from members, that his experiments were not directed to ascertaining the absorbent quality of the material; but from what he had observed, he was not inclined to think it was of an absorbent nature, and his opinion was confirmed by the facts he had stated, as to the vases filled with water, not being injured by the frost.

Mr. C. MAY said, it was true that some of the specimens appeared to be porous and would in reality be so, unless the connecting medium was either sufficient in quantity to fill up the spaces between the particles of sand, or sufficient force was used to press all of them into intimate contact with each other. It did not, however, follow, that even if it did take up a certain quantity of water, it would necessarily suffer from frost. A good stock brick would absorb a considerable quantity of water, and yet it resisted frost perfectly. He believed, that any material would be broken up by the frost, only when it contained a very considerable proportion of moisture, in comparison to its substance, and when the adhesive strength of its cementing medium was less than the expansive power of the water converted into ice. As this artificial

stone, therefore, evidently had very minute pores, he contended, that it might be pervious to moisture, and yet resist frost perfectly.

Mr. CARPMAEL observed, that the spaces between the particles of sand were cells, which remained unfilled by the silicate and contained air, which had not been expelled by the process of working and baking. It was evident, therefore, that the structure was cellular, rather than porous, and that the quantity of moisture contained in these cells was so small, that the frost would not have any effect upon the mass.

Mr. NEWTON submitted, that sufficient distinction had not been drawn between porosity and absorption; they were in his opinion very different qualities. The former would result from a cellular structure, and any moisture taken up, would be contained in the vacuities between the particles; whilst the latter arose, from the entire substance being of a nature to permit the admission of water into the particles of which it was composed. The artificial stone being formed of grains of silicious sand, incapable of absorbing water, and being further cemented together by a medium, which in the process of baking was fused and became an insoluble glass, might certainly be a porous substance; but it could never become absorbent, like a mass of baked clay, in which moisture would be equally distributed throughout every particle. He therefore contended, that the distinction he had made should be borne in mind, in arguing upon the quality of the material under discussion.

Mr. J. J. HAWKINS drew the attention of the meeting to a paper on a somewhat analogous subject, "The formation of Concrete," read by him at the meeting of the British Association at Cork, in 1843.

The practical position he there assumed was, that the proportion of one-eighth part of lime, generally used in concrete, was uselessly large, and in fact, that a considerable portion of lime was objectionable, and contributed but little to the strength and compactness of the mass. He argued from experiments upon piles of spheres of various diameters, showing, that the smaller ones were required to be arranged in the interstices between the larger; that if greater attention were paid to screening the shingle and the sand, so as to produce the proper varieties of size, almost universal contact between the stones might be induced, and it was evident that system must produce a firmer mass. He suggested, that in making concrete, the slackened lime should be brought to the consistency of cream, the sand should then be first mixed intimately with it, then the smaller gravel, and ultimately the larger shingle; working the whole well together, so that every particle might be thoroughly

coated with the lime; whilst the interstices would be regularly filled by the pieces of stone of corresponding dimensions, and they would all rest upon each other, instead of upon the lime, which would only be used for holding the mass together. One part of lime, to twelve parts of shingle and sand, he had found, under such treatment, would compose a concrete, which in eleven days had become harder, than specimens of a mass of Roman brick and concrete mortar, or than a very superior specimen of a portion of the foundation of a wall at the East India Docks, which had been built thirty years, and had been exhibited some years ago, at the Institution of Civil Engineers. He was of opinion, that one part of lime would suffice, if properly worked up with twenty parts of shingle and sand, to form a very strong concrete.

No. 779.—Mr. John Richmond, (of Bow, Middlesex,) exhibited and described an Engine Counter on an improved principle.

MANY of the engine counters usually employed are complicated in their construction, or are uncertain in their action, independent of being very expensive, when they are made in a superior manner for special services; such as for indicating the number of strokes made by pumping engines, where the quantity of water raised is required to be estimated; or for marine engines, making Transatlantic voyages, such as the "Great Western," the "Great Britain," &c.

These considerations induced the author to combine a counter possessing the following advantages:—

The number of strokes made by the engine can be read off at one view without calculation. The leading, or unit hand, traverses the entire circumference of the large dial, and the hands of the three small dials, Nos. 2, 3, and 4, all revolve in the same direction.

The first motion is given by a sliding bar and fixed spring, instead of by a double pallet, so that it is impossible that the first wheel can be thrown more than one tooth, by one stroke of the engine.

No skip-wheels are employed, and the hands are all moved by a train of wheels and pinions, so that the motion is regular and progressive.

It will be seen that the arrangement is very simple,—

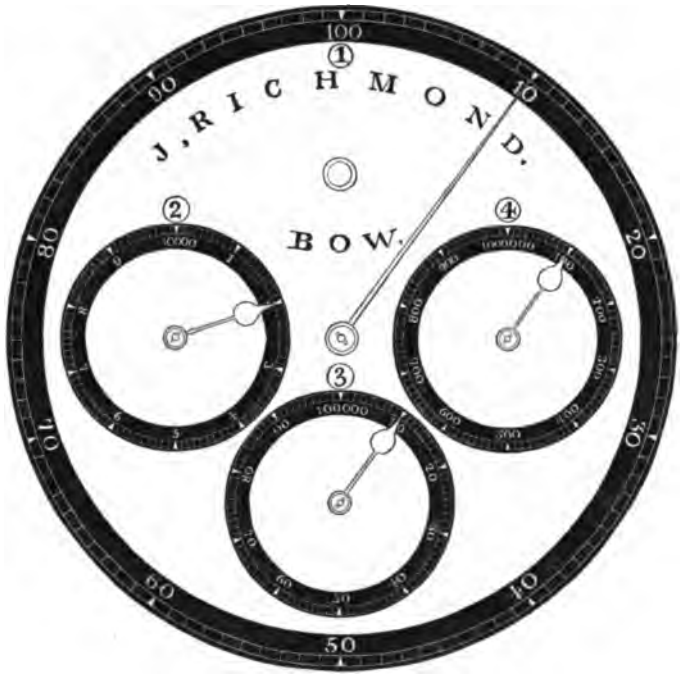
No. 1, or the large circle dial, contains 100 divisions, and the large hand traverses one division at each beat, or stroke.

No. 2 dial also contains 100 divisions, each one of which is equi-

valent to one entire revolution of No. 1 hand, thus enregistering 10,000.

No. 3 dial is divided in the same manner, enregistering 100,000; and

No. 4 dial, also divided into 100 parts, enregisters 1,000,000.



Thus any amount can be read off without any possibility of error.

These counters have been rather extensively used, and it was in consequence of the general approval of their action by engineers that the specimen counter was submitted to the Institution.

Mr. SIMPSON, *V.P.*, said he had used Mr. Richmond's counters for some time, and had found them much more correct than the ordinary counters, with which errors not unfrequently occurred, particularly in reading them off. The sliding bar and spring, and the internal wheelwork, insured accuracy in the beats, and the arrangement of the dials enabled the engine-men to read the numbers off with

facility. He was so satisfied with them, that he intended using them with all his engines.

Mr. WICKSTEED had generally used the common Boulton and Watt counters, and had found them uniformly correct; but he admitted that errors sometimes occurred from carelessness in reading off the quantities. He had never seen any instances of their slipping, even when the engines were going fast. He had not examined Mr. Richmond's counters, but was ready to adopt them, or any others that would insure greater accuracy of registration.

Mr. FAREY thought it was of great importance to obtain very accurate counters, and, for that reason, he had advocated the adoption of those expensive machines which had been employed on board the "Great Western," and other long-voyage steamers. He liked the apparent simplicity of Richmond's counters, and thought they were instruments likely to be very useful, particularly for pumping engines.

Mr. FIELD, President, said it should be observed, that the action of this counter was a kind of dead beat, which was likely to be very precise and accurate, and would preclude the possibility of the slipping, which had been complained of in the ordinary counters. The comparatively low price (£7.) was an additional advantage, and would no doubt contribute to its being extensively employed.

Mr. LLOYD agreed in the propriety of all steam-vessels having counters on board; and he thought, from the apparent simplicity of construction of the counter under discussion, that it would prove a useful instrument.

ANNUAL GENERAL MEETING.

January 18, 1848.

SIR JOHN RENNIE, President, in the Chair.

Messrs. R. Davison, G. A. Jermyn, and J. B. Redman were requested to act as scrutineers of the ballot for the election of the President, Vice-Presidents, and other Members and Associates of Council, for the ensuing year.

The list of the attendances of the Members of Council for the past year was read, and the ballot was commenced; the balloting papers being sent for examination at intervals of fifteen minutes, in order to expedite the labours of the scrutineers.

The Annual Report of the Council on the proceedings of the Institution during the past year was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council to be printed and circulated with the Minutes of Proceedings in the usual manner.*

The Telford Medals and Premiums, and the Council Premiums, which had been awarded, were presented.†

Resolved,—That the thanks of the Meeting are due, and are presented to Messrs. T. H. Wyatt and W. Newton for the readiness with which they undertook the office of Auditors of Accounts, and for the clear balance-sheet‡ they have laid before the Meeting; and that Messrs. W. Newton and J. Wright be requested to undertake the office of Auditors for the year 1848.

Mr. Newton returned thanks.

Resolved,—That the thanks of the Meeting are justly due, and are presented to the Vice-Presidents and other Members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal in behalf of the Institution.

Mr. J. Locke, M.P., returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Sir John Rennie, President, for his strenuous efforts in the interest of the Institution, for his extraordinary attention to the duties of his office, and for the urbanity he at all times displays in the Chair.

Sir John Rennie, President, after returning thanks, addressed the Meeting on many points of interest to the profession of Civil Engineering, and took leave of the Members on vacating the Chair, which he had filled for three sessions.

Resolved,—That the President be requested to permit his Address to be printed, and circulated with the Minutes of Proceedings in the usual manner.§

Resolved unanimously,—That the cordial thanks of the Meeting be given to the Secretary, Mr. Charles Manby, for his unwearied zeal and attention to the interests of the Institution, the ability displayed by him in the general execution of his duties, and his constant readiness to lend his individual assistance to members of the profession.

The Secretary returned thanks.

The ballot having been open more than an hour, the scrutineers, after examining the papers, announced that the following gentle-

---

* *Vide* ante, page 1. † *Vide* ante, page 2. ‡ *Vide* ante, page 20.
§ *Vide* ante, page 27.

men were duly elected to fill the several offices in the Council for the ensuing year:—

President.

JOSHUA FIELD.

Vice-Presidents.

William Cubitt.	James Simpson.
James M. Rendel.	Robert Stephenson, M.P.

Other Members of Council.

Members.

John F. Bateman,	Charles May.
George P. Bidder.	John R. M'Clean.
Isambard K. Brunel.	Joseph Miller.
Joseph Cubitt.	William C. Mylne.
Joseph Locke, M.P.	Thomas Sopwith.

Associates.

John Clutton.	Thomas H. Wyatt.

Resolved,—That the thanks of the Meeting be given to Messrs. R. Davison, G. A. Jermyn, and J. B. Redman, the scrutineers, for the promptitude and efficieney with which they have performed the duties of their office; and that the ballot papers be destroyed.

February 1, 1848.

JOSHUA FIELD, President, in the Chair.

The following candidates were balloted for and duly elected:—

Patrick Moir Crane, Thomas Cundy, Jun., Michael Scott, Charles Heard Wild, and George Harrison, as Associates.

Mr. Field addressed the Meeting, on taking the Chair for the first time since his election as President.

Resolved,—That the President be requested to permit his Address to be printed and circulated with the Minutes of Proceedings.*

The discussion upon Mr. F. Ransome's paper (No. 774) "On the production of Artificial Stone," &c., was continued and extended to such a length as to preclude the reading of any communication during the evening.

---

* *Vide* ante, page 32.

February 8, 1848.

JOSHUA FIELD, President, in the Chair.

No. 780.—" Account of the recent Improvements in the Drainage and Sewerage of Bristol."* By James Green, M. Inst. C. E.

At a time when the attention of the Government, and of the public, is so universally directed to the sanitary condition of the cities and towns of the kingdom, and to the consideration of measures of improvement, a statement of what has been done during the year 1847, by the Town Council of Bristol, towards the improvement of the drainage and sewerage of that city, may not be uninteresting.

Bristol is generally known to have been, for many years past, in a state requiring the most serious attention to its drainage and sewerage. Previously to the construction of the docks, or rather of the floating harbour for the shipping, that city, like other places similarly situated, possessed an outlet, for all its sewage, into the tideway of the river Avon, and the noxious effluvium from such sewage was, in a very great degree, prevented, by the regular action of the tides; but, on the formation of the floating harbour, about the year 1805, this natural outlet was diverted; because when a dam was formed across the old tideway of the river, near the Hotwells, the former bed of the river Avon, above that place, became the floating harbour, and a new channel was cut for the waters of the Avon, from Totterdown to the tideway, below the new dam.

It is very extraordinary, that in forming this floating harbour, no means, or precautions were taken, to intercept and carry off the sewage of the city, independently of the dock float. The consequence of this omission was, that the whole of the sewage, to the extent of not less than twenty thousand tons of solid fetid matter, per annum, was carried into the float, whence, even now, it is only carried off by the occasional scourings resorted to by the Dock Company, for the purpose of preserving the required depth of water in the floating harbour, which may, in general, be considered as a stagnant pond of water. It is true, that this pond is supplied by the waters of the river Avon; but still, during dry and hot seasons, the fetid vapours

* The discussion on this paper extended over three evenings, but an abstract of the whole is given consecutively.

arising from it, are sufficient to prejudice seriously the health of the inhabitants residing in its vicinity.*

To the quantity of sewage, thus brought into the float, must be added that which is brought down, by the river Froome, into the north-western branch of the float at Stone Bridge, near St. Augustine's Back, from which spot its upward channel extends about one mile and a half, in a north-easterly direction, as far as Baptist Mills, and, in the lower half of its length, traversing the most populous and crowded part of the city, receiving in a very narrow channel, all the sewage produced from a considerable distance on each side of it. The effects of these accumulated masses of filth, delivered into the float, became at last so intolerable, that the Dock Company, in the year 1822, was compelled, by mandamus, to take some steps for the abatement of the nuisance, and, that arising from the river Froome being considered the most material and important, an entirely new sewer was laid down, under the direction of Mr. Mylne, from a point in the Froome, immediately above Stone Bridge, passing in the line of and beneath the Broad Quay, under the bed of the float, below Prince's-street bridge, and delivering itself into the new cut made for the Avon, opposite the new county gaol. Tide gates were placed at the arch of Stone Bridge, to prevent the water from being drawn out of the dock float, when the new sewer was used, and a sluice was erected at the head of the sewer, to be opened as occasion might require.

This was a very judicious and effective work, for its extent; as the sewer intercepts the side, or transverse sewers, which before emptied themselves into the float, along the Broad Quay, and under proper management, would discharge much of the sewage of the Froome, which was previously carried into the float. It was also well calculated to afford the means of considerably abating the nuisances arising in the general course of the Froome, had the improvements, of which the channel itself was then capable, been carried into effect; these, however, were entirely lost sight of, and, notwithstanding the great expense which the new Town Council have, since that time, incurred, for the further improvement of the Froome, nothing of consequence was effected, until recently, beyond arching over certain parts of the channel, where such works were indispensable.

The river Froome is somewhat peculiar in its character; the quantity of water brought down by it, in the summer season, is very

* *Vide* Report of Sir H. De la Beche and Dr. Playfair to the "Health of Towns' Commission," 1845.

inconsiderable; but, as the channel, above Baptist Mills, receives the waters of an extensive tract of hilly country, the river, after rain, becomes quickly swollen, and rises to such an extent as to overflow its borders and occasion considerable floods in the lower part of its course, within the boundary of the city; so that when, by the formation of the floating harbour, the waters of this stream were deprived of free egress to the sea, the utmost attention was necessary, to preserve the course of the stream in such a state, as would enable it properly to carry off, not only the flood waters, but the sewage also. Nothing, however, was done for the accomplishment of these objects, and the channel remained for a series of years wholly neglected. The consequence of this was, that the debris brought down by every succeeding flood was deposited in the channel, forming, in some parts, considerable shoals, whilst in other parts deep pits were scoured out, at the same time greatly disturbing the course of the stream, which should have been preserved in as direct a line as possible. In fact, the bed of the river was raised, in some places, to such an extent, that in dry seasons, the usual quantity of water in the stream, after filling the pits, could only find its way to the lower parts of the stream, by percolation through these shoals, and the sewage delivered into the channel, on each side of it, was allowed, during such times, to accumulate on the verge of the stream, to a frightful extent, until the next floods would carry it off.

Thus the channel of the river, which, from Philadelphia-street Bridge to Stone Bridge, was of very unequal width, varying between 16 feet and 40 feet, and confined on each side by the walls of houses, warehouses, and other buildings, almost all very densely inhabited, became, in fact, only an extensive cesspool, or a large open sewer, for the reception of masses of filth, poured into it from each side, which, during dry seasons, the common stream of the Froome was not sufficient to flush, or scour away, even if the channel had been free from obstructions. The effects upon the health of the inhabitants of the adjacent districts, caused by the miasma from these fetid accumulations, are most graphically described in the reports of Sir H. De la Bèche and Dr. Playfair, to the Health of Towns' Commission, in 1845.

These deposits of debris, and the encroachments made on the channel of the river, had the effect of increasing the height and extent of the floods: for, in some parts, the bed of the stream had been raised, by the deposits, full 4 feet above its proper level; this was especially the case in the Broad Weir, in which place, the river, being wider than in many other parts, deposits had been made full 5 feet higher than the ancient bed of the stream: this deposit

was facilitated by the obstruction occasioned by the bridge at Castle Mill-street, which consisted only of two arches of 6 feet span each, with a pier of 6 feet wide between them. Here it may be proper to observe, that on, or about this site, there formerly existed a mill. It appears, therefore, that what is now considered to be the main channel of the Froome was not so formerly; but what is now called the back stream, or ditch, about eighty yards to the north-west, was the main course, and it is probable, that what is now considered the main stream, was a leat, or lead, made for the purpose of supplying this mill with water. It has, however, for ages, been considered the main channel, and, as it is the only course for the river Froome, from Baptist Mills to the Dock-float, it must be treated and dealt with as such.

In the course of the year 1846, the state of the sewerage had become so obnoxious to the whole city, that the Town Council appointed an especial committee, to investigate the subject of drainage and sewerage, and in the month of September of that year, the Author was instructed to survey the state of the Froome, and to advise as to the measures necessary for abating, and if possible, removing, the serious nuisances resulting from the state of that river. He accordingly examined very carefully the channel of the river, and all the circumstances connected with it, and reported very fully on the subject to the Drainage Committee, on the 30th of October of the same year.

His report recommended the straightening of the course of the river, and the deepening of its bed, so as to effect a properly graduated fall therein, contracting the channel at the same time as far as possible, to a regular width, by means of walls along the sides, so as to give a generally uniform power to the scouring waters; appropriating the channel of the river for a pure water-course, by constructing side sewers for the reception and carrying off the sewage, independently of the stream; at the same time providing a sufficient quantity of water for effectually scouring, or flushing away, the deposits, as well as keeping up a constant and uniform stream of water through the lower parts of the river, in dry seasons.

To effect the last-mentioned object, it was necessary to devise some means of obtaining more water than the river Froome itself would produce, in dry seasons; this could only be done by drawing water, when required, from the upper dock-float, through the ancient castle moat, at the head of Broad Weir, for the purpose of scouring the channel from that place to Stone Bridge; the most infected and noisome part of the stream. This, on the Author's examination,

was found perfectly practicable, although it had previously been declared impossible.

This report was unanimously approved; but, inasmuch as the carrying it out, to the full extent, would involve a very serious expense, and would require legislative powers, which the Town Council did not possess, the same report suggested a minor plan of improvement, which was not liable to the same objections, although it was not quite so perfect in its character.

Even this minor plan was, however, considered by the Committee to be beyond the power of the Town Council to accomplish, without legislative authority; and, pending the knowledge of what might be required by the Bill, at that time before Parliament, for the improvement of the Health of Towns, it was thought prudent to suspend the proceedings for a while; but, the necessity of taking immediate steps, for the relief of that part of the city adjoining the Froome, and lying between Broad Weir and Stone Bridge, becoming daily more imperative, the Author received instructions, in January, 1847, to re-survey, and report what plan he should consider best adapted for the earliest possible removal of the nuisances, which affected the populous district between Stone Bridge and the Castle Moat, arising from the state of the river Froome, and the probable additional expense which would be incurred, in consequence of that portion of the improvements being carried into effect in the first instance.

A report was, therefore, made by the Author, in accordance with those directions, and the works recommended by him were, on the 16th of March 1847, unanimously directed by the Town Council to be forthwith carried into execution.

These works comprise,—1st. Scouring the bed of the channel from Stone Bridge to the head of Broad Weir, at the Castle Moat, and so deepening it, that at the Castle Moat, the bottom of the channel should be 2 feet 6 inches below the level of the dock float, with a properly graduated fall throughout.

2ndly. Contracting the channel, so as to give, as nearly as possible, an uniform width of about 20 feet, by means of stone walls, built perpendicularly, to the average height of 3 feet, forming paved slopes of stone, from the tops of those walls (at an angle of one and a-half horizontal to one perpendicular,) to the walls of the buildings behind them, and laying open tile gutters in the slopes, to convey the contents of the several side, or transverse sewers, directly into the stream of the channel.

3rdly. Taking out the pier of Castle Mill-street Bridge, substituting one arch, and removing other obstructions.

4thly. Removing the solid stone weir across the mouth of the

Castle Moat, the apex of which being 4 feet above the level of the dock float, prevented all escape of flood waters, through the Castle Moat, until they had risen to that height, and erecting in its stead a new weir of 50 feet in length, the apex of which is only 1 foot above the level of the dock float; in this weir there are six cast-iron sluices, or hatches, each 3 feet wide and of corresponding height with the solid part of the weir, their bottom being 2 feet 6 inches below the level of the dock float, and corresponding with the bed of the deepened channel. Thus an escape is provided for the flood waters, 50 feet in length, instead of 20 feet (as before), and at 1 foot above the level of the dock float instead of 4 feet; whilst the discharge of water may be further increased, by drawing up the hatches. By means of these hatches water is drawn out of the upper dock float, through the Castle moat, into the bed of the Froome, for the purpose of scouring, or flushing, when there is a deficiency of water in the Froome itself. This weir, in some more than ordinary floods which have occurred since its erection, has, from its extended length and its diminished altitude, been found materially to lessen the height of the water in the upper parts of the river.

5thly. Deepening and widening the Castle moat from Tower Hill to Broad Weir, in order to give a free and adequate flow of water (when required) into the bed of the Froome at Broad Weir.

6thly. So far deepening the bed of the river, above Philadelphia-street Bridge, as would allow the waters of the Froome, in ordinary times, to flow into the stream below that bridge, in aid of the water drawn from the dock float.

7thly. Cleansing out and repairing what is called the Dock Company's Culvert; which was laid down in the year 1815, at the expense of the Corporation. This extends from the Castle Moat, a little below the weir, under the bed of the stream in Narrow Weir, and under Philadelphia-street, into the back stream, for the purpose of scouring it, as it was well calculated to do; but the channel, or moat, through which the water was to pass, appeared to have been wholly neglected, and the back stream had been allowed so to be choked up by the continuous deposit of stones, gravel, and silt, that the culvert was rendered wholly inoperative, and had itself become nearly, or quite, closed up, and the hatches which were erected at its entrance had gone entirely to decay.

This culvert has been cleaned out, new hatches have been erected, and the back stream having been sufficiently deepened, the culvert has been brought into perfect operation by water being drawn through it, from the dock float, for the purpose of scouring the channel below.

On cleansing and perfecting this culvert, it was found necessary, somewhat to modify the works recommended by the Author, in his first Report for the improvement of the upper part of the Froome; by erecting a weir in the archway of Philadelphia-street Bridge, instead of above it, as was at first intended; this alteration afforded the means of preserving the full area of the culvert, whilst the ultimate object of the weir was fully answered.

In deepening and widening the Castle moat, the Castle walls adjoining it on the western side were found so dilapidated, that in order to support them, it became necessary to arch over the channel of the moat. This so far increased the width of the Corporation property, adjoining Lower Castle-street (which is very narrow) as to afford the means of widening that street nearly 12 feet, which is a great public improvement.

The confining the channel to its proper width through the Broad Weir, afforded an opportunity for widening the street full 5 feet on its north bank, which was accordingly done, and the sharp turn out of this street into Lower Castle-street was taken off, by widening the lower side of Philadelphia-street Bridge, by cast-iron girders, placed in an oblique direction. These measures, independently of the improvements of the River channel, are universally acknowledged to be important City improvements.

It will be readily conceived, that the works could not be carried into execution, in the order in which they are mentioned.

The primary object of the Town Council and Committee was the production of benefit to the most seriously affected district, in as short a time as possible, and before the hot weather set in, and as this could only be accomplished, by obtaining an additional and ample supply of water from the upper dock float, the attention of the Author was, in the first instance, applied to the deepening and widening the Castle Moat, the construction of the weir and the sluices, deepening the river through Broad Weir, and removing the obstruction occasioned by the state of Castle Mill-street Bridge. These works were, from their nature, slow in progress, and from unfavourable weather, for some weeks after their commencement, and other unforeseen causes, the works were not in a state to permit water to be drawn from the dock float until the 16th day of July, by which time the Committee had become so impatient of delay, that it was resolved at once to draw the sluices, regardless of the consequences which might ensue from the non-completion of other works.

The sluices were accordingly drawn on that day, when an ample flush of water issued instantaneously from the dock float, into the

bed of the Froome, sufficient to carry before it the accumulated filth in the channel below and to force it through 'Mylne's' culvert, under the bed of the float, into the new cut, and this notwithstanding the shortness of the time allowed for preparing the bed of the stream, below Castle Mill-street Bridge, to receive such flushing.

The result of this experiment being satisfactory to the Committee, to many members of the Town Council and other influential inhabitants of the City, induced a confidence, that on the completion of the works, as far as they had been then authorized to proceed, they would answer all the purposes anticipated.

At this time, the bed of the stream required to be cleansed, deepened, and contracted to its proper width. To carry on these works, and, at the same time, to preserve the scouring of the channel for three hours, on every successive tide, (which the inhabitants of the district had been led to expect), became an object of deep anxiety to the Engineer; for the postponement of the completion of these improvements of the lower parts of the channel, would have occasioned great additional expense, and have endangered the stability of the works already finished; but he succeeded in making arrangements with the owners of Baptist Mills, under which he was permitted to impound the water during the day, and to work it down in the night. Thus he was enabled to prosecute the works, and to give an effectual scour of water, through the channel of the river, for three hours in every twelve hours; which proved sufficient for flushing away the filth in the stream, and keeping the channel clear.

The execution of this work was necessarily attended with considerable expense; as time pressed, and the atmosphere in the channel, in which the men were obliged to work, was so vitiated, that they could with difficulty be kept to it, and then only by those stimulants, which the nature of the work required, and the more so, as on many occasions they were obliged to work by night, and in many cases to use torches, or candles, during the day, in the parts of the channel which had been arched over; but by dint of perseverence and exertion, the whole of the works which had been thus undertaken, were accomplished and brought to a close, in a manner satisfactory to the Committee, as expressed in their Report of the 25th of September.

So far then, the Town Council and the Drainage Committee have the satisfaction of seeing, that they have succeeded in removing the greatest nuisance which perhaps was ever experienced in Bristol, or any other city, as is fully acknowledged by the inhabitants at large.

The estimate of the cost of these works, delivered to and sanctioned by the Drainage Committee, amounted to £4825. 13. 2.

The actual expenditure upon them, under all the disadvantageous circumstances alluded to, amounted to £4537. 2. 8.

It is true, that the works hitherto completed, have been productive of benefit to only a limited portion of the inhabitants of the city; but that portion is the one which has been most seriously affected and prejudiced, by the proverbially foul state of the Froome. Much more, however, remains to be done, for fully carrying out the improvements of the Froome, which were recommended in the Author's reports. He has, by direction of the Drainage Committee, reported his opinion of what ought to be done, in addition to what has already been accomplished; but these works cannot be carried into execution without the authority of Parliament. Should, however, the suggestions of the Author be approved and be carried into effect, he ventures to predict, in spite of the apparent difficulties attendant upon all attempts to improve it, that the river Froome, which has for the last half century been considered as the bane of the City of Bristol, will be found, not only capable of perfect control; but of affording the best possible means of improving the drainage and sewerage of those parts of the city, and the suburbs, bordering on, or connected with it.

The paper is illustrated by a plan of Bristol, showing the general system, and those parts that are executed, and is accompanied by an Appendix, containing the Reports of the Author and of the Drainage Committee, &c.

The Rev. the DEAN of WESMINSTER said, that some years ago, when, in conjunction with the Rev. Mr. Conybeare, he was engaged in the production of an account of the geology of the country around Bristol, he carefully examined the localities alluded to, and had witnessed the nuisances arising from the defective drainage, so well described in the paper. These, no doubt, had increased every year, until they had become unbearable, and the public health demanded an expenditure for the amelioration of the system, which would in a great measure have been avoided, if proper steps had been taken at an earlier period; because much of the mischief had arisen from the accumulation of debris brought down by floods from the country around, and which being deposited in the course of the stream which formed the natural drain of the district, raised its bed, to the extent that had been described, and then all the other evils followed. There was every reason for believing, that even in the olden days, Bristol was deficient in drainage, and though it was a

delicate subject for abstract speculation, he could not help thinking, that the absence of female beauty which was so remarkable, as to have induced the passing of a law in the time of Queen Elizabeth, granting the freedom of the city to any man who married a Bristol woman, might in some degree have been caused by disease, engendered by the miasma arising from want of proper drainage. He had always remarked, that in impure air and bad situations, the human form was imperfectly developed, and there was an absence of beauty.

The general arrangement in Mr. Green's system appeared very well combined; but there was one point, which forcibly struck him, as worthy of adoption, wherever it was practicable. He alluded more particularly to the power of flushing the main bed of the Froome, at regular periods, by opening sluice-gates which admitted the waters of the Avon. He would direct the attention of Engineers to the inquiry, whether it would not be practicable to introduce the waters of the Thames, at some point sufficiently high up, to enable them to pervade the whole range of the metropolitan main sewers, and thoroughly cleanse them at least once in every twenty-four hours.

If he should not be considered as diverging too much from the subject, he would direct the attention of the meeting, to the defective state of the lighting of some of the thoroughfares. Lighting was intimately connected with sewerage, and when the ways were cleansed, he hoped they would not forget, that it was necessary to enlighten the paths. He observed, that on Westminster-bridge, and some other public places, an inferior kind of triple cockspur burner, with three distinct jets of flame, was used; he contended, that in the present state of science this was unpardonable; for it was well known, that if instead of having three distinct jets, they were so placed as to unite and form one sheet of flame, a much more powerful light would be obtained with the same expenditure of gas. This the Reverend Dean demonstrated, by Leslie's gas burner, wherein, when the points were bent backwards so as to separate the jets, the effect was much less powerful, than when they converged, and the jets mingled so as to form one sheet of flame; this he contended was the best proof of the disadvantages of the triple jet burner, which he was shocked to see, not only on Westminster-bridge; but also at the office of the Gas Company, where he expected to have found in use only the best examples of all kinds of really improved apparatus. He must repeat his expressions of disappointment at finding those, who should be optimists

in all things connected with their calling, contented to be pessimists, and setting the bad example of using an almost pre-Adamite form of burner.

It must be evident to the meanest capacity, that when the jets of flame were distinct and separate, the combustion could not be so perfect, and, consequently, the light would not be so intense as when the edges of the jets were in contact, mutually assisting each other; and, by the combination, increasing the general intensity of combustion. This principle had been well demonstrated by Sir Humphry Davy; and it must be clear, that while augmenting the amount of light, there would not be anything like a corresponding increase in the quantity of gas consumed. He hoped, that the Commissioners of lighting would speedily do as he had done at Oxford, nearly thirty years ago, when he was chairman of the Gas Company there,—throw aside the triple jet, and adopt the motto of "*tria juncta in uno.*" He apologized for thus diverging from the subject of the paper; but he considered the subject of lighting to be so intimately connected with sewerage, that he could not help mentioning what he thought such flagrant defects; but which could be so easily remedied.

The public paid heavy rates for lighting and cleansing the streets, and they had at least a right to demand, that the best means should be employed for giving the full amount of light and cleanliness that was required.

Lord ROBERT GROSVENOR, M.P. had listened with much interest to the description of Mr. Green's works at Bristol, and offered his congratulations upon the apparent success attained. It appeared, that the chief object of Engineers, in laying down general plans of sewerage, was to take advantage of the ebb and flow of the tide, in order to get rid effectually of the products of the sewers. It had, he believed, been proposed to use the body of fluid, contained in the King's Scholars' Pond Sewer, for flushing such of the other sewers as were at a lower level than it was. There could be no doubt, that the primary object should be the removal of everything that could place human life in jeopardy, and if the only end to be attained, were the mere removal of the contents of the sewers, nothing could be so effective as flushing them with large volumes of water, and making the outlet sufficiently far down the river to gain considerable inclination; but he would remind the meeting, that from statements which had been made public, it appeared perfectly compatible with public salubrity, to preserve and make beneficial use of the manure deposited in the various conduits, and instead of, as at present, pouring it

into the rivers, destroying the fish, and forming shoals of fœtid matter on the borders of the streams, to make use of it for agricultural purposes. He trusted, that the attention of Engineers would be fixed upon this desirable end, and if a portion only of the same skill, which had been so eminently successful in the great public works of this country, was brought to bear upon this subject, he felt assured, that the noxious matters, which were at present the sources of disease and death, would be not only displaced, but would be rendered useful in fertilizing the fields, and at the same time be a source of profit to those who directed their attention to the subject.

Mr. GREEN said, in answer to questions from Captain Moorsom, that although in his original design he had not contemplated the collection of the matter from the sewers, and using it for agricultural purposes, yet such an arrangement was perfectly compatible with the executed works and the proposed extensions. The object of the works was to remove the former deposits by the simplest means, and to prevent the recurrence of the nuisance, and no system was so effectual as flushing at regular intervals. He was of opinion, that in all designs for the sewerage of towns, the main object should be to carry off with rapidity the contents of the sewers, and then, if it were possible, or profitable, to afford every facility for making use of the manure for agricultural purposes; this, however, he thought, was a secondary consideration, when compared to the health and comfort of the public; but if it could be made pecuniarily advantageous, individuals would be found who would accomplish it.

Mr. SMITH (of Deanston), said, that the mode which Mr. Green had followed, in providing for the flushing of the sewers of Bristol, and for getting rid of the deposit, seemed to have been conducted very skilfully, and so far, he thought, that praise was due to him for it. But he must be allowed to say, that in the present day, any plan for merely getting rid of the manure from the sewers, by pouring it into the river, was imperfect. He felt confident, that by good engineering, a system could be arranged, by which the whole of the valuable matter might be made available for agricultural purposes. Many plans had been proposed, and some had been executed, for precipitating and de-odorizing the matter of cesspools and drains, so as to convert it into a dry portable manure; but he felt satisfied, that no mode was so practicable and cheap as pumping up the sewage matter from the town, sending it through pipes to the adjacent country, and there distributing it over the land. For the perfect sewerage of large towns, both as regarded cleansing and the proper saving of the refuse for agricultural purposes, means must be pro-

vided for conveying a plentiful supply of water to every domicile, and thereby washing all the refuse through well-trapped air-tight pipes, and he felt assured, that if the Metropolis was properly managed in this manner, the air of the streets, courts, and alleys, would be nearly as sweet as in the country.

A company had been formed in the Metropolis, for conveying away, by means of pipes, the sewage matter for agricultural purposes. He knew, from his own experience, that there was no difficulty in pumping sewage water; but that, in fact, it was nearly as easy as pumping common water. There might occasionally be some little annoyance from the silt, or from cinders floating in the water; but these difficulties might be obviated by proper attention. The main point was to examine into the great advantages which would arise, from efforts to effect the management of the sewage water in this manner.

The Reverend the Dean of Westminster had spoken of the gas, and of the burden of rates for lighting and cleansing, but Mr. Smith contended, that if the sewage water of London were preserved and applied to agriculture, it would go far to annihilate the necessity of rates altogether. To accomplish this would certainly require time; but he hoped the forthcoming measure for the improvement of towns, would advise more attention to regulating the management and disposal of the sewage water. He trusted, that advantage would be taken of all the mechanical and chemical skill, which had lately been brought to bear upon the subject, and if the first attempts were successful, there could be no doubt that the system would be quickly extended over all the great towns of Europe. He might appear too sanguine; but he argued from the observation of facts, and from practical experience, and after having made experiments which convinced him, that the same system, which applied the sewage water successfully to one acre, might be equally successful, when applied to a hundred thousand acres.

He had computed the value of the sewage water which was now thrown away. The urine, for instance, which was the most valuable, was almost entirely lost. If proper urinals were provided, for the convenience of pedestrians, whence the urine could be conveyed into proper pipe sewers, the sewer water would be rendered three times more valuable than it was at present. An estimate of the probable value of the sewage water thus lost showed a return of £1 per head, per annum, for the whole number of the population. This, for the metropolis alone, would amount to a very large sum.

The sewage water had been used for irrigation for nearly a hundred years, on some meadow ground near the city of Edinburgh,

greatly increasing its annual value, although it was there used extravagantly, for want of proper dilution. There were about five hundred acres so irrigated in the neighbourhood of that city, for which an average yearly rent of about £30 per acre was realized, and he felt confident, that if the liquid was properly diluted, it might be applied with equal success to ten times that quantity of land; for the sewage water, when not greatly diluted, was too strong for the plants; it therefore acted as a poison, and in some instances killed many of them.

The most perfect application of the sewage water, with which he was acquainted, was to be found on the Duke of Portland's estate, near Mansfield. That town contained about ten thousand inhabitants; but, being an old-fashioned country town, there were many dunghills behind the houses, and a considerable portion of the water from the houses was thrown upon these dunghills, so that the sewers did not receive as much sewage water as if a complete system of house drainage had been established. Nevertheless, the addition of that sewage water, small as it was, to the water of a considerable brook, which flowed through the town and afterwards through the meadows, had the effect of raising the value of four hundred acres from 4*s.* 6*d.* per acre, to from £5 to £15 per acre. The land was straightened on the surface, laid off in terraces, with a gentle slope, in some instances, he believed, not more than half an inch in 30 feet; whilst the channels for conveying the water were formed so wide and open, that the grass grew as well upon the bottom and sides of the channels as upon any other part of the meadow. The practice was, to give the land a thorough drenching, which was accomplished by allowing the water to flow over it for the short space of twenty-four hours; this, however, had the effect of producing most luxuriant crops, which were generally ready for cutting in about six weeks after the application of the water, and four, or five very heavy crops of grass were cut every season. The soil consisted of an open loose sand, with from an inch to an inch and a half of earthy matter on the surface, in which the roots of the grasses were thickly imbedded, and a few straggling roots were found passing down into the sand.

In order to dispose of the sewage water of London, or of any large town, it would require to be conveyed to a considerable distance, so as to obtain a sufficient area of land to consume the manure; and this could only be done cheaply by the system of pumping and conveying it in pipes, which would embrace the further advantage of the distribution upon the land in an equal manner; this could be most readily accomplished, by having hose

pipes, of from four to eight hundred yards in length, to convey it from the service pipes to any part of the field, and there, by jet, or otherwise, to distribute it over the surface of the land. Liquid manure could, in this way, be transported ten miles, or more, and be laid upon the surface for less money than it would cost to carry solid manure from the farm-yard and distribute it upon the ground. He believed the expense would not exceed 2*d.* per ton; but if it cost 6*d.*, or even 1*s.* per ton, it would be cheap. He had three years' experience of pumping, transmitting, and distributing liquid manure, on a farm near Glasgow, through pipes of 4 inches and 5 inches diameter, to a distance of about a mile, without any material obstruction of the pipes having occurred. The effects were most marked. Luxuriant crops of grass existed, even during the winter months, and heavy crops of turnips and grain were obtained. It was remarkable also, that crops, which had from some cause been checked in their growth, were invigorated and restored, by a shower of the liquid, and afterwards grew most luxuriantly.

He felt satisfied, that it would be found profitable to lay down pipes, even for the application of common water in dry seasons. There was therefore great encouragement to Engineers, to give due attention to the subject.

Mr. WICKSTEED said, he had not intended to have spoken; but he could not let it be supposed, that Civil Engineers were indisposed towards, or ignorant of, the plans that had been proposed, for using advantageously the products of the sewers. Many Engineers had directed their attention to the subject, with reference to London alone. The late Mr. Rennie had a comprehensive scheme, and more recently, the plan proposed by Mr. Martin had been considered by Engineers. Mr. Wicksteed's attention had been very carefully devoted to it, both for the Prussian Government, when he was requested to lay down a system for the sewerage of Berlin, and also for the London Sewage Company, to whom, in 1845, he made a detailed Report,* which was in the Library of the Institution, and to which he would refer the members rather than absorb their time in describing his views.

It would suffice to state, that considering the quantities of cultivated and uncultivated land in England, as estimated by MacCulloch, to be:—

---

* "Report upon the various Plans proposed for rendering available the Manure contained in the Sewage Water of the Metropolis," &c. By Thomas Wicksteed. Tract, 8vo. London (R. Kinder), 1845.

	Acres.
Arable land . .	13,252,000
Pasture . . .	12,380,000
Uncultivated . .	6,615,680
	32,247,680

and supposing the supply of sewage water north and south of the Thames to be 96,776,830 tons per annum, the Report showed, that this quantity would suffice for manuring 8,000,000 of acres; but that the cost of laying down pipes for the proper distribution of such a quantity would be so great, that the scheme was not practicable, if it was based upon the plan of having an intercepting sewer, with a fall equal to the natural fall of the land, or of the Thames at low water.

It then proceeded to suggest a plan of advantageously conveying the sewage water of London "by means of a system of pumping-engines and pipes, analogous to that of the great water companies." The outline of this was to construct a large intercepting sewer, at an average fall of 12 inches per mile, through a main line, on each side of the Thames, causing all the existing sewers to empty themselves into them. These main conduits would terminate at points low down the river; say Barking marshes on the north side, and Greenwich Marshes on the south side. At these spots, powerful engines would be employed for pumping up the solid and liquid matter from the pits, at the extremities of the main sewers, to such a height, as to permit the former to be separated in reservoirs, whilst the latter would run into the Thames at all times of the tide. The solid deposit in the reservoirs would be removed, and if necessary dried artificially, compressed, and packed for easy transmission by land, or water. It was shown, that in the sewers of London, there was one part of solid matter to eleven hundred and twenty parts of liquid. By adding one part of lime, to two thousand eight hundred parts of crude sewer water, a quantity of ammonia (valuable fertilizing matter), would be further deposited.

Such were the general details for London, and the plan he had proposed to Major Byron, for the sewerage of Berlin, was very similar, because the flatness of its situation rendered any natural drainage nearly impracticable. In that locality, however, by the system proposed, not only would the solid matter have been well disposed of; but, by raising the liquid portion to a sufficient height above the surface, it could have been advantageously distributed over a tract of uncultivated land, which it would have fertilized and rendered productive.

He felt some hesitation in speaking of systems proposed by other

Engineers; but prompted from conviction of the correctness of his calculations, and relying upon his experience as an Engineer for water companies, he felt obliged to record his opinion, that any plan of distributing liquid manure through pipes among fields, or even the market gardens in the immediate vicinity of London, could not be remunerative. If it was not found remunerative to lay down pipes, for supplying water and gas to houses situated at short distances apart, was it probable that it could pay, to lay pipes for distributing liquid manure over necessarily greater areas? It was entirely a question of cost of outlay, and it was in the power of every Engineer to satisfy himself upon the subject. He should, at the same time, compare the cost of distributing the liquid manure, with that of the solid compressed residuum, which could be disposed of with a good profit at from £2 to £3 per ton, and was stated to be nearly equal in fertilizing qualities to guano, which had been sold at from £10 to £15 per ton. He must state, that he was indebted to Mr. Aikin for much assistance, when examining the subject, which he considered was one of great importance, particularly at this moment, and the consideration of it at the Institution, would, he hoped, have beneficial effects.

The Reverend the DEAN of WESTMINSTER, at the request of the President, stated, that he had recently paid some attention to the use of various deodorizing fluids, when emptying cess-pools. By the courtesy of Mr. Chadwick, a gang of men, with the proper implements, had been sent to the Abbey precincts, and had there emptied seventeen cesspools, under the Dean's own inspection.

The mode of proceeding was very simple; when the cesspool was opened, a ladder was let down, upon which a man stood, and, with a pole, agitated the matter, whilst another sprinkled over the surface, from a small garden engine, a constant shower of Sir William Burnett's deodorizing fluid, composed of 1 lb. of chloride of zinc to 50 lbs. of water. This fluid, acting by contact only, absorbing the sulphuretted hydrogen, as it was evolved from the agitated mass of fœtid matter. At the same time, a suction pipe was lowered into the cesspool, and a sufficient quantity of water being added, the contents were pumped out and discharged at the rate of one cubic yard in 34 minutes, using 9½ pints of Burnett's disinfecting fluid.

The success of this system of clearing out cesspools appeared certain, for not the slightest stench escaped during the process, and the expense, as compared to that of the old mode, was greatly reduced. Under the ordinary system the cost would have been nearly £3 each. Even at present it was reduced to about 15*s.* 6*d.* each, and when the men were better accustomed to their work and had

better implements, the expense would probably be reduced to 10*s*. each. He must not be understood to be an advocate for tolerating the existence of cesspools, and he only interested himself in these experiments, to be satisfied of the practicability of emptying them without infecting the whole neighbourhood. He must declare, that the process was very successful and should be very generally employed.

The subject of sewers was so extensive that he should scarcely know where to break off, if he went into the system generally. He must, however, draw attention to the open sewers which were still allowed to exist amidst a dense population, spreading disease and death around. Many of them existed in Westminster. It would suffice to mention two; one was between the Penitentiary and Alderman Johnson's stone yard, and as it was perfectly stagnant for a considerable period during every tide: the exhalations from it were most pestiferous. The other was close by Buckingham Palace, and although more screened from observation than the former, was but little less noxious.

With respect to the ordinary sewers, it appeared to be generally admitted, that unless such a copious supply of water could be obtained, as would remove all the solid matter, flushing must be resorted to as the easiest and the most efficacious modeof disposing of the contents. If it could be satisfactorily shown, that the diluted matter could be advantageously employed for agricultural purposes, by distributing it over the land, as had been mentioned, he would view such a desirable improvement with satisfaction; but it must first be shown, that there was land so situated as to receive it, and then, that it could be distributed without pipes, which, it appeared to him, must be so costly as to prohibit profit.

The case of the meadows near Mansfield was, he contended, a very peculiar one, and should not be quoted as a general argument. The cost attendant upon the plan had been infinitely beyond the means of private individuals. The Duke of Portland had expended an enormous sum upon it, and he could not have accomplished his object at all, if Mr. Gally Knight had not sold him the property intervening between Mansfield and the land in question. It was true, that by the system, a comparative desert had been converted into productive grass land, and the formation of meadows, in a valley traversing the sandy region of Sherwood forest, had caused to be converted into arable farms, large tracts of the forest, which otherwise could not have been cultivated. This was, he repeated, a special case, and was not of general application.

Such a case as that near Edinburgh could only occur, where large towns stood in elevated positions, from which the water could descend

and irrigate the subjacent meadows, without the aid of machinery; but if the liquid matter required to be pumped up and conveyed in conduits, he was convinced the scheme would never be remunerative. It had been stated, that the value of the manure, now lost in the sewers, was the tax paid by the cities of London and Westminster for health and cleanliness, and he thonght, that any one who had resided in any of the continental cities, which did not possess the advantage of sewers, would willingly accord with him, in desiring rather to extend the benefits of such cleanliness, rather than in hope of gain, by the use of the exuviæ, to run any risk of deteriorating rather than improving the present system.

The Reverend Dean had felt it is duty to oppose strenuously, the movements of a company, proposing to establish a manufactory of "poudrette," where the exuviæ was to have been baked, and prepared for easy transit. The intended situation was precisely in the line of the prevailing wind, in the neighbourhood of the Houses of Parliament, and the chimney for carrying up the stench from the ovens, was designed to be exactly of the height of the tower, by the top of which Dr. Reid proposed to obtain pure air, for warming and ventilating the new Houses of Parliament. He regretted to be under the necessity of speaking disparagingly of any new undertaking; but when there was a chance of the public health being interfered with, he felt that it became the duty of every man to offer his unprejudiced opinion, and in this case, he had no hesitation in resisting the establishment of such a nosegay, as was intended for the noble lords and right honourable gentlemen.

Mr. Peto, M.P., said, he trusted, that such a nuisance, as the spreading liquid manure over the land in the immediate vicinity of London, would never be tolerated. He was well acquainted both with the meadows near Mansfield and near Edinburgh, and must say, that however great might be the agricultural advantages of the system, it would be dearly purchased if the whole region near any town were infected, like the two places he had mentioned. The inhabitants of London, who were confined in crowded streets by their daily occupations, should, on the contrary, have every opportunity afforded them, of obtaining fresh air (if possible) in their immediate neighbourhood; but if the air in the vicinity of all large towns was to be rendered like that of the Mansfield and Edinburgh meadows, the direst consequences might be anticipated. He feared, that no disinfecting fluid would suffice to remedy such an evil, and he trusted that no prospect of gain would induce the introduction of a system which must be prejudicial to the general health of the public.

Mr. J. Simpson, *V.P.*, said he had examined the works described

in the paper, and could vouch for the great improvement, already effected by Mr. Green. The subject of sewerage was one to which Mr. Simpson had paid much attention, and he had read carefully the report of the evidence given before the Commissioners on the Health of Towns. He must say, that he was disappointed with the report, and disagreed with the Commissioners in the result they arrived at. It had been stated, or at least implied, that neither the Architects, or the Engineers were acquainted with the laws governing the conveyance of fluids. Now, on the other hand, it would not be difficult to show, from the printed evidence, that the exploded dogmas of the old writers on hydraulics, had been received and adopted, rather than the more modern formulæ derived from better theoretical knowledge and greater practical experience. He hoped these questions would be discussed carefully before the Institution, and he felt convinced, that an intimate knowledge of both the theory and the practice of their art, would be exhibited by the Civil Engineers who might take part in the discussion.

Mr. E. CHADWICK thought, that in the previous part of the discussion, an erroneous impression had been conveyed, in presuming, that the refuse of a small town was at all similar to that of a large city. In the former case, the domestic refuse, the stable products, and the contents of the cesspools, were specially applied; whilst, in the latter case, a considerable portion of the products of all kinds were allowed to pass off into the sewers. Under this erroneous view, the cases of the Mansfield meadows and of the land near Edinburgh, had been received as identical. Now he had examined both localities, and must state, that, in his opinion, there was scarcely any similarity between the circumstances. The Mansfield land appeared to him a simple case of water meadows extremely well prepared, regularly laid out, &c., favourably situated for receiving the contents of a considerable brook, which previously traversed the town of Mansfield, and brought down with it whatever refuse was projected into its channel. During storms it became more densely charged with fertilizing matter, because quantities of refuse, which at other periods were out of the reach of the stream, were washed into it by its tributaries. The slightest smell had never been perceived at Mansfield; for the matter was so extremely diluted, that any influence by it, upon the atmosphere, was nearly impossible. The case was widely different at Edinburgh: the land there received, in an almost undiluted state, the produce of the sewers and of the surface drains, which, from the peculiar position of the city, terminated upon the land in question, and where, no doubt, the effluvium was very offensive. If, however, a larger quantity of water was

used for domestic purposes in Edinburgh, and was directed through the drains upon these lands, not only would the noxious smell be diminished; but the fertilizing quality of the fluid would be increased.

It was erroneous to suppose, that the produce of the sewers of London at all resembled that of even Edinburgh. It was proved, beyond doubt, that the refuse of not one-half, and, he might say, not more than one-third, of the houses, was conveyed into the sewers; but the rain and the overflow of all the water for domestic use was carried off by them, and hence the nightsoil was so diluted, that it might be conveyed along any conduits, and projected to any distance, almost with the same facility as the water was conveyed by the water companies.

The evidence of the Dust Contractors shewed, that no market could be found for a large portion of the more solid refuse; in fact, that it would not pay for removal, and the immense accumulations in the lay-stalls, in some degree, proved their statement. The great expense of its conveyance to any distance into the country, and of its subsequent application to the land, prevented the agriculturists from attempting to employ it. The evidence of the police, as to the surreptitious means adopted for getting rid of these matters, further corroborated the fact. Still, the value of exuviæ as manure, could not be denied, when the example of its effects upon the agriculture of Holland, Belgium, and Germany, was brought forward. There, liquid manure was carefully accumulated and was advantageously used as a dressing, although expensively distributed upon the land, from water-carts, or even by manual labour, and spread with scoops. It was evident, that, in these cases, for the sake of economy, the liquid manure must be used in too great a state of intensity, and the evidence upon this subject, of all the best agriculturists and horticulturists, showed not only that it was preferable to apply manure, in a liquid state; but that it should be much diluted. It was certain, that moisture was necessary, to enable plants to imbibe the fertilizing portions of solid manure, and it must be evident, that it was more rational to distribute it at once in a liquid state. The question of the most convenient and least expensive method of doing this, had, he presumed, been well considered by those who proposed to embark their capital in such an undertaking.

He thought, that the objection, as to any exhalations arising from the application of liquid manure, was unfounded; in fact it could not be so prejudicial, as the effects of the application of solid manure of any kind, which, when it was left to decay upon the

surface of the ground, must, in the course of its decomposition, infect the air, and produce disease; indeed, complaints had frequently been made, of the deleterious effects upon the air in the neighbourhood of Hyde Park, whenever a top dressing of manure was given to the grass. In Kent, where fish was used as manure, the effects were very deleterious; fever constantly appearing at the season when this dressing was applied. Independent of these considerations, it was shown also, that a large portion of the value of the manure was carried off by the atmosphere during its decomposition, for it depended upon the rain to carry it into the ground to the roots of the plants; whereas, when it was applied in a liquid form, it was absorbed immediately by the soil, without evaporating any of its valuable qualities.

He had seen several instances of wonderful results, from this mode of manuring. There was a case in Scotland, where twenty-seven acres of land were so poor, that two cows could be barely fed upon them. Upon the same estate, about forty cows and four horses were kept in stalls; their dung was received into a tank, into which a rill of water was conducted, and from thence it was distributed, by the natural inclination of the ground, over these twenty-seven acres of poor land, which now produced four immense crops annually; whilst some little knolls, situated in these fields; but which could not receive benefit from the liquid manure, remained nearly as sterile as before.

Returning, however, to the sanitary question, he must repeat his conviction, based upon direct experience, that if the land was well drained and the liquid manure was sufficiently diluted, there would not be any noxious effluvia; and he felt sure, that if in the cases he had mentioned, of deleterious effects arising from the use of solid manure, a large quantity of water had been employed, the same result would have been obtained, as at Manchester, where an experiment was made, by diluting three loads of night-soil with seventeen loads of water, and in a few hours after its distribution upon the land, no odour was perceptible.

The comparative expense to the farmer, of the distribution of this liquid manure, was a point of importance; it appeared, that about twenty-four loads could be distributed by pipes and hose for one shilling, whereas the general cost for distributing such a quantity, with a horse and cart, would be about seven shillings; and if the poaching of the land were considered, the expense would be about ten shillings per acre.

Dr. URE said, that the purification of towns from the filth, daily engendered in them, and from the malaria resulting from its putre-

factive decomposition, seemed to him an object strictly appropriate for discussion by the Institution of Engineers, or at least one towards the due accomplishment of which, they should co-operate with Chemists. The former body should devise the most appropriate systems of ventilation, drainage, and transport, and the latter, the means of neutralizing and destroying noxious effluvia, and counteracting putrescence. He would therefore offer a few remarks on certain chemical preparations, which had been recently pressed on public attention.

The first was the Nitrate of Lead of M. Ledoyen. This substance had been proposed as a disinfecting and deodorizing agent, on the score of the affinity which it possessed for sulphuretted hydrogen; a fœtid gas, which was exhaled, generally, from putrefactive animal substances, and also from cabbages, onions, and from most of the cruciform plants, in a state of decomposition.

Against the employment of the nitrate, acetate, or any other preparations of that metal, there were, in his opinion, three valid objections:—1st, their costliness; 2nd, their poisonous properties, when swallowed, even in small quantities; and 3rd, their feeble deodorizing power.

The second deodorizing preparation, was the Chloride, or Muriate of Zinc, as proposed by Sir William Burnett, which had been extensively employed for destroying the fœtor of the bilge water of ships. This substance exercised very considerable influence in such cases, as also in abating the nauseous smell of night soil. The zinc base of the compound, might be regarded as combining with, and fixing the sulphuretted and phosphuretted hydrogen of the putrescent mass, while the muriatic acid seized and condensed the ammonia. The comparative high price of this preparation, and its corrosive and poisonous operation on living animals, would, however, probably prevent its introduction to any great extent.

The third class of deodorizing agents, consisted, chiefly, of certain saline compounds of Peroxide of Iron, and Protoxide of Manganese; introduced about twelve months ago, by Mr. Brown, and applied recently by Messrs. Ellerman and Co. In Dr. Ure's opinion, the chloride and pyrolignite of the red oxide of iron, seemed entitled to the preference over other substances, hitherto recommended, for arresting putrefaction and abating its offensive exhalations, as its power was equal to the standard solution of chloride of zinc, and it was at the same time infinitely cheaper, while it was not liable to any poisonous misappropriation. It had a remarkable power of coagulating semi-liquid night-soil, and of counteracting the putrefaction of blood and other offal of slaughter-houses. The

preparation could be procured in any part of the kingdom at all times, and might be safely used by the common scavengers, with the best results. If a few gallons of it were introduced by them daily into every putrefactive mass, throughout the towns and cities of the kingdom, a surprising improvement would immediately take place in the salubrity of the air, breathed by the dense sickly population. The chemical products he had prescribed were strictly indigenous, and could be manufactured, in various parts of the kingdom; and in particular, at Manchester, Newcastle, Liverpool, and Glasgow, at a very low cost, if required for very extensive disinfecting purposes; the price in London, at present, was eighteenpence per gallon.

The only consideration to be taken into account, in applying such deodorizing preparations to night-soil, dunghills, &c., was, whether their utility as manures, might not be impaired. In this point of view, nitrate of lead and chloride of zinc were not free from objection; as it had been ascertained, that compounds which were poisonous to animals, were also injurious to plants. The only possible objection to the employment of the salts of peroxide of iron, was their supposed tendency to interfere with the efficacy of the phosphoric salts, always present in animal excrement. The notion that the rust in wheat was caused by phosphate of iron, arose merely from a vague surmise suggested by the colour, and was now exploded by chemical research.

Exact and elaborate researches into the composition of the excrement of animals, had been lately made in the laboratory of Giessen, by Mr. John R. Rogers, under the guidance of the great analyst, Baron Liebig. They proved beyond all doubt, that the excrement of swine, oxen, sheep, and horses, contained very large quantities of phosphate of iron; for example of the ashes of the excrement of the

Hog . . .	there are	10·55°
Ox . . .	,,	8·93°
Sheep . . .	,,	3·98°
Horse . . .	,,	2·73°

and they all contained a little manganese. Mr. Rogers ranked the phosphate of iron among the soluble portion of the ashes, because it dissolved in a small excess of acid. In Ellerman's liquid, there was abundance of acid in the ferric salts, to render the phosphate of iron soluble in water, and therefore nutritious to plants. In the excrement of the hog and the cow, nearly the whole of the phosphoric acid present, existed in combination with red oxide of iron.

As the subject of gas lights had been incidentally introduced,

perhaps he might be permitted, in corroboration of the observations of the Dean of Westminster, to direct the attention of the Members to the investigations of Sir Humphrey Davy, which, although made long since, when gas lighting was comparatively in its infancy, were singularly correct in their inferences. His propositions were, that the amount of light was in proportion to the intensity of the combustion, and that the heat evolved was also in proportion to the light produced. Subsequent experiments had, however, shown, that the combustion might be carried too far, and that beyond a certain point the light was not augmented in proportion to the intensity of the combustion. This was demonstrated by partially closing, with a metal disc, the orifice of the long straight chimneys over the burners; the draught was thus diminished, but the light was increased; it was evident, that, in this case, the oxygen of the air was enabled to combine with the carburetted hydrogen, in a better proportion, and in a manner better suited to produce combustion. Several burners had been invented, whose construction was based upon this principle; among them he would mention the Universal Burner,* and the National Economic Burner, as, in his opinion, the two best he had examined.

Mr. C. MAY begged to remind the speakers, that the paper they had been called upon to discuss, treated of the improvement of the method of draining and removing a serious nuisance from a city, where the sewerage was notoriously deficient, and upon which subject he, in common with many others, hoped to have received much information, from the able and experienced Engineers he saw around him; but the discussion appeared to have assumed a tone, which, however interesting to a Farmers' Club, or a Horticultural Society, was, he submitted, scarcely suited for a Meeting of Civil Engineers, where he had expected to have heard the subject of the plans for the sewerage of cities and towns ably discussed, leaving to others the task of discussing the methods of disposing of the contents of the sewers, and the probable produce of the land, to which the manure was applied. He regretted that this opportunity of eliciting valuable information, on so important a point, should not have been taken advantage of, and thought it was scarcely fair treatment of Mr. Green's valuable paper, as it was evident, that the subject had, in his hands, received great attention, and the result appeared to be so satisfactory, that a careful investigation of it, and a discussion of the general subject, would have been productive of great benefit.

* *Vide* Minutes of Proceedings, 1846, vol. v. p. 433.

Mr. F. Braithwaite claimed the indulgence of the Meeting, for attempting to answer the objections advanced against the commercial application of sewage manure, and he would rather have wished to leave the matter in the hands of Mr. Smith, (Deanston,) who, from his experience, would have treated the subject better. He thought the question should be treated both chemically and commercially.

Some of the first practical chemists of the day, such as Brande, Cooper, Miller, and others, had carefully considered the subject, and had determined, by analysis, that every 500 tons of liquid manure, contained 1 ton of soluble and insoluble matter, in mechanical suspension and chemical solution, and that such ton of matter was divisible under three heads: 1st. the earthy carbonates and sulphates, such as carbonate of lime, sulphate of lime, ammonia, magnesia, and silesia; 2nd, animal and vegetable matter in mechanical suspension; and 3rd, the ammoniacal and other salts in chemical solution; the proportions in each, say in 5,985,500 tons of liquid manure, taken from samples from the King's Scholar's Pond sewer at various times, during a period of twenty-four hours, would be 2,892 tons of earthy carbonates and sulphates, 1821 tons of animal and vegetable matter, and 7258 tons of ammoniacal and other salts.

The money value of those products was estimated as follows:—earthy carbonates and sulphates, 10*s.* per ton; animal and vegetable matter, £3 per ton; and the ammoniacal salts at three times the value, per ton, of poudrette, say £8: 5. per ton (equal to guano).

It would follow, that the value of the whole would be thus:—

No. 1.	2892 tons,	at 10*s.*	per ton	£1,446
2.	1821 ,,	£3	,,	5,463
3.	7258 ,,	£8 : 5	,,	59,878
	11,971			£66,787
	500			
	5,985,500			

It had been estimated, that the whole of the London sewage was 96,000,000 tons annually; it would be seen, that the King's Scholars' Pond sewer would represent about one-sixteenth part of the whole quantity; therefore, if the above quantities were multiplied by 16, the product would be the value of the whole sewage manure of the metropolis; assuming, of course, that all was equal to the samples from which the analysis was provided.

As to the practicability of the scheme in a commercial point of view, that point had been considered by eminent engineers; he might quote Mr. Smith (of Deanston,) Mr. Mylne, and Mr. Hawkesley.

Mr. Smith shewed, that the liquid manure could be delivered profitably, over 25,000 acres, between London and Hounslow, at 2*d.* per ton; but Mr. Mylne, preferring to be on the safe side, considered that 3*d.* per ton ought to be the price, if delivered over 35,000 acres, upon which he had based his calculations. Mr. Mylne stated, that he considered the farmers would gladly pay 4*d.* per ton.

Mr. Mylne's opinion was corroborated by Mr. Hawkesley. The latter gentleman had previously given evidence before the Health of Towns Commission, and stated,* that at Nottingham the Water Company would supply a heavy shower of water equal to a depth of one-sixteenth of an inch over an acre of ground for 2½*d.*; and it scarcely required to be conversant with agriculture to know, that at certain periods the farmers would gladly pay a hundred times such a sum, for such a shower of rain.

Mr. Hawkesley also stated, that one man could, with a proper distribution of pipes, water 20 acres in a day.

After the evidence that had been given, of the chemical and commercial value of sewage manure, and the favourable decision of the Committee upon the Sewage Bill, it was hardly fair, upon only a cursory examination, to arrive at an adverse conclusion.

He considered the question was of vital importance, and was well worthy of the consideration of Civil Engineers, who had hitherto been too much engaged on railways and other works, to attend to sewerage; but he thought, that agricultural engineering and the improvement of the sewerage of towns, well deserved their consideration; and he felt sure, that when either the Government, or private enterprises demanded their assistance, the Civil Engineers would be found not only to possess all the requisite knowledge; but would be quite ready to devote their time and talents to the subject.

He had carefully read the last Report from the Commission of the Health of Towns, and could not find such depreciating paragraphs as had been mentioned, although he agreed, that it would have been better taste to have expunged some passages relating to the works of individuals.

Mr. Wicksteed could not agree, that only the constructive parts of the subject should be considered at the Institution; for although

* *Vide* Report of Health of Towns' Commission.

it was not essential for a Civil Engineer to be a Chemist, or an Agriculturist, he would be a better general adviser, if he possessed an adequate knowledge of these, as well as of other branches of science; at all events, he considered, that it was incumbent on an engineer, in laying down plans for the sewerage of a town, to ascertain whether the products of the sewers could be advantageously made use of, and at what cost, in order to advise his employers as to the plans to be adopted.

Mr. Wicksteed then recapitulated the principal points of his former speech, as it appeared to have been, in some points, not fully comprehended; and he begged it be understood, that the advice he had given to a public company, relative to pumping up the sewage water, was based solely upon mercantile considerations, and without any reference to sanitary measures.

He at first calculated upon the principle, that if water could be profitably distributed over an acre, it could be delivered over 100 acres, or any greater quantity, with corresponding advantage; but his subsequent investigations demonstrated the fallacy of such reasoning, and the statements he had already made, did, he must submit, corroborate that position. The quantity of sewage water produced from London alone, would suffice for a very considerable extent of agricultural district, and the pipes must be of such a size as to entail an amount of first outlay which would, in his opinion, render any hope of profitable return perfectly fallacious. However, these points were not within the province of the Institution to discuss, and he would not enlarge upon them.

It was a flagrant error to suppose, that Engineers either had not directed their attention to the best forms and dimensions of sewers, or the general arrangement of a comprehensive system of sewerage; the question was extremely simple, and the rules were plain.

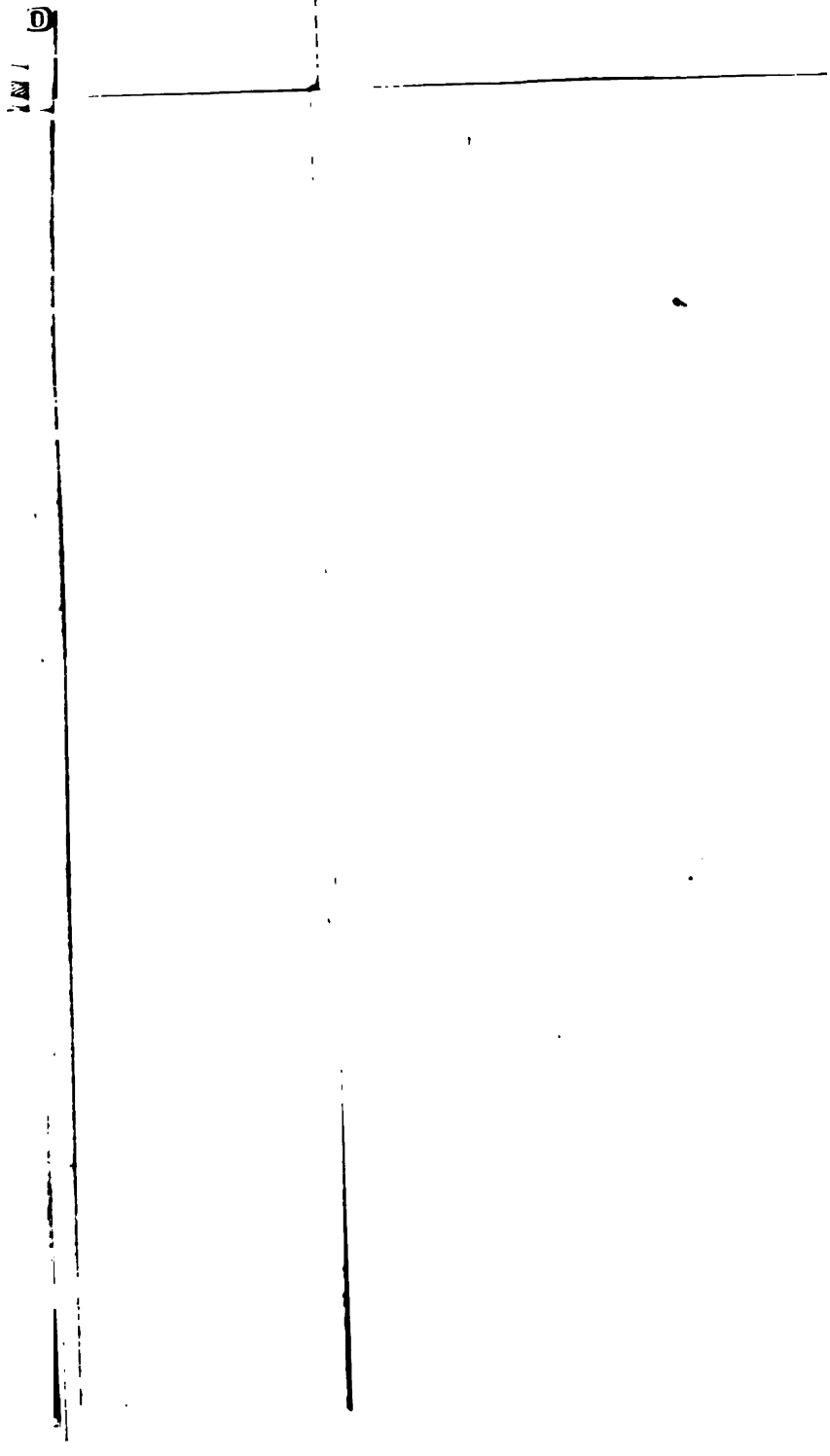
The proposition for substituting circular sewer pipes, of small diameters in certain situations, for the present sewers, was no doubt feasible, provided they could be kept clear of foreign and solid matters; but when cloths, dead animals, grease, &c., passed into them, and much fall could not be given to them, they would soon be stopped up. Again, when they required repairs, small sewers would be found, he feared, considerably more expensive. There could be no doubt of the advantages of the egg-shaped sewer, and of getting the rapid current of water into the narrowest part, when the stream was shallow, in order to carry away the deposit of sand and granite brought from the macadamized roads and the pavement, and small dimensions would suffice, if the quantity of fluid was always uniform; but in the case of sudden storms, space must be provided for carrying off the

great increase of fluid, and also, as in high tides, provision must be made for the sewers being transformed into reservoirs; this might, however, in a great degree be provided for, by having the outfall lower down the river. There were numerous other points connected with the subject of the sewers, which were too important to be entered upon at the end of a discussion, which had already taken so wide a range; he suggested, therefore, that another opportunity should be afforded for the full discussion of the engineering portion of the question—of the distribution and construction of sewers.

Mr. WALKER regretted having been absent at the commencement of the discussion, as he would have preferred making his observations upon the subject of sewers generally, before the conversation had diverged to the appropriation of the products of the sewers, instead of being restricted to canvassing the systems of drainage and sewerage hitherto employed under various circumstances.

The subject had recently engaged the attention of the public and of the Legislature, and Reports had been published of the results of the inquiries of the Commissioners, which latter, however, Mr. Walker might venture to state, did not appear to contain any very novel matter. Still, it was probable, that some good might result from this demonstration of the interest felt on the subject by the Government, and more, from its directing the attention of the authorities of other cities and towns, to the importance of establishing an efficient system of drainage, upon the best known principles, just as the publication of the late Mr. M'Adam's writings and the Parliamentary inquiry, benefited the roads all over the kingdom, not so much from the novelty, or the peculiarity of the system proposed, as by impressing forcibly upon the Trusts and Parishes, the actual bad state of their thoroughfares, and demonstrating the necessity, as well as the economy, of adopting a good system of permanently improving them, in order to keep pace with the times.

The tendency of the Report of the Commissioners, was to overstate the defects of the present drainage and sewerage of the metropolis, and to encourage an opinion, that but little had been done to ameliorate the system, and that little not upon scientific principles. Now, Mr. Walker contended, that however far from absolute perfection, the conduct and measures of the late Commissioners of Sewers might have been, it must be remembered, that, whatever had been done, was by their orders, and the credit was due to them. When, therefore, it was considered, (as was in fact, universally allowed,) that the existing provisions for the sewerage and drainage


D
N

of London, were infinitely superior to those of any other city in the world; that the system pursued had been the constant subject of inquiry and of imitation by foreign Engineers and Architects, who had admitted, that the generally healthy state of the metropolis was chiefly due to the efficient sewerage and the copious supply of water to the habitations; that in the restoration of the City of Hamburgh, Mr. Lindley had taken, as the general basis of his plan, the system pursued in London, grafting upon it modern improvements, of which, from the peculiar locality, it was susceptible, it was unjust to deny some merit to the late Commissioners.

Mr. Walker had been in the habit of comparing the provisions for sewering, watering, and lighting the metropolis, to the arteries and veins of the human body, and his views accorded with those of the late Dr. James Johnson, who, in one of his interesting works,* said,—

"The Cloaca Maxima, with its former ramifications, which penetrated under some of the principal streets of ancient Rome, has induced inconsiderate observers to form too high an estimate of the cleanliness (as they have done of many other virtues) of the old Romans. If the arms of the Cloaca Maxima extended to many, or even all the streets of the eternal city, the purification of Rome, by means of common sewers, can bear no comparison with that of London. Neither in ancient nor in modern times did the sewer of the street communicate with the houses, except in very few instances.

"The great improvement in British cleanliness and health, was not known to the ancient Romans, and is not practised by the modern inhabitants of the eternal city, except on a very contracted scale,—I mean the private conduits from the houses leading to the common sewers in the streets. If drains permeated all the streets of Rome (and they are only to be found, I believe, under some of the principal ones), the benefit would be nothing, compared with that resulting from the individual conduits from each house, as in London. This is the grand source of cleanliness, comfort, and salubrity."

In the recent Report of the Commissioners, reference was made to the evidence given by Mr. Walker on the subject, in the year 1834. He was somewhat at a loss to understand why the opinions given by him so long since, should have been brought forward now, unless it was for some purpose not generally apparent. What he said at that time had reference more especially to the Commissioners of the Westminster Sewers, whilst the late Mr. Saunders was the Chairman, and he would repeat, that a great debt of gratitude was due to that gentleman, for his devotion of time and energy to the improvement of the sewers. The plans which were introduced under his auspices, and those of the Commissioners, and the manner in which

* *Vide* "Change of Air; or the Pursuit of Health and Recreation," &c. By James Johnson, M.D., page 137. 8vo. London. Third edition. 1833.

they were executed, might not have been perfect, but great amelioration had been affected; large works had been completed, and the ground work had been laid, for the eventual perfecting of the general system. He thought, therefore, that the present Commissioners might, without prejudice to their own talent, have found something to praise in what had been done, and that they might have been a little less indiscriminate in imputing blame and want of knowledge, as in these days of reform, their successors might not find all that they had done, replete with wisdom and science.

In the year 1847, Mr. Walker was appointed one of the Commissioners for inquiring into the Bill for the Improvement of the Kent and Surrey Sewers, and on that occasion, the evidence of Mr. Gwilt and Mr. I'Anson, the surveyor, differed in some respects from that of other professional men, who had been examined under the Parliamentary inquiry.

The section of the first class sewers, was stated to be formed by a semicircle, of 18 inches radius at the bottom, with nearly vertical sides, of 2 feet in height, and completed by a semicircular top, also of 18 inches radius; making the main dimensions 5 feet high by 3 feet wide. As compared to conduits of these proportions, he could not perceive any great practical advantage in the egg shape, with the small end downwards, as was proposed. Nor did he think the general size of the sewers was too great, for it must be remembered, that many of them were situated below the high-water level of the Thames, and that during the time of the tide being above their outfall, they became reservoirs for the sewage and the up-land waters, which otherwise would flow back into the cellars and basements of the houses. On that account it had been found necessary to increase the size of the lower end of the King's Scholars' Pond sewer, which, for a length of about a mile, was left open, and had at its junction, the tide-gates and sluices that had been constructed under Mr. Walker's direction.

The Report of the Commissioners recommended, as the dimensions of the first class sewers, 6 feet in height by 4 feet in width; so they evidently recognized the principle of large dimensions in some cases, although they ran into the opposite extreme, in recommending small circular water-tight sewer-pipes, of glazed earthenware, or glass, instead of their being constructed of brickwork as at present. If the only object of the sewers was to convey away the water, &c., from the houses, these small impervious tubes would, undoubtedly be the best, provided they were not less than 8 inches in diameter; but the main object of a well-combined system of sewers, was to afford the means of effectually

draining the whole ground whereon the houses were built, and as was known generally in all sewers, and was fully appreciated by Sir M. Isambard Brunel, in his labours at the Thames Tunnel, the greatest quantity of moisture rose from below, into the beds of rivers, the system was adopted, of laying the bottom course of brickwork of the sewers dry, and only setting the inner ring in cement, thus enabling a constant percolation of the land drainage along the line of the sewers. If therefore, they were made perfectly water-tight, one of the great objects of the sewers would be defeated, and the city would be enveloped in miasma. The King's Scholars' Pond sewer, which he had before-mentioned, drained the whole district through which it passed. This was shown, very distinctly, by an experiment that was tried some time since, when it was supposed, that the ornamental piece of water in the grounds of Buckingham Palace, rendered that building damp. In order to test this practically, Mr. Walker, as a member of the Commission, had a hole dug, midway between the palace and the pond, and it was found that no water came in, until the excavation arrived at the level of the bottom of the King's Scholars' Pond sewer, far below the bottom of the pond, and then it all rose from beneath, and did not enter by filtration from the sides.

The part of the Regent's Park, which was situated upon the clay, was considered less healthy than that upon the gravel, solely because the drainage from the former, along the line of the sewers, could not be so perfect as that of the latter.

As Mr. Walker had before quoted Dr. Johnson, he might perhaps be permitted, in conclusion, to read another extract from the same work,* in which he treated the subject of sewerage in his usual felicitous manner.

"With the fortunes of Rome, Cloacina also departed. She scaled the Alps, and halted in Southern Gaul; but there, no one would erect to her a temple. Then, as now, the Gallic votaries of Cloacina preferred the open air for offering up incense at her shrine. Driven from the banks of the Tiber, and finding no place of retirement on the Continent, the goddess crossed the Channel—fixed her residence on the banks of the Thames—and has now, in modern Babylon, five hundred thousand temples erected to her worship! The oracles of her high priests may be consulted in Greek-street, Soho."

---

* *Vide* "Change of Air; or the Pursuit of Health and Recreation," &c. By James Johnson, M.D., p. 136. 8vo. London. 1833.

February 15, 1848.

JOSHUA FIELD, President, in the Chair.

The discussion upon Mr. Green's paper (No. 780), "Account of the recent Improvements in the Draining and Sewerage of Bristol," was continued, and extended to such a length as to preclude the reading of any communication during the evening.

February 22, 1848.

JOSHUA FIELD, President, in the Chair.

No. 783.—"On Submarine Foundations; particularly the Screw Pile and Moorings."* By Alexander Mitchell, M. Inst. C.E.

THE entire subject of the methods of preparing submarine foundations, if treated of in as general and comprehensive a manner as its importance demands, would not only far exceed the limits of a paper for the Institution of Civil Engineers, but would be tedious and unnecessary, as the majority of the members are thoroughly conversant with the various systems in their daily practice; it is proposed, therefore, to limit the present inquiry to a cursory mention of the ordinary methods, and to devote the greater space to a description of the Screw Mooring and the Screw Pile, and of the works in which they have been employed.

Sheet piling, whether of wood, or iron, is now familiar to every one, as the driving it is an operation of daily occurrence, and the numerous scientific treatises on stone foundations, placed in positions of peculiar difficulty and danger, render all comment upon them quite superfluous.

The Edystone and Bell Rock Lighthouses furnish splendid examples of such works. The scientific skill employed in joining and binding together their parts, giving to them almost a monolythic solidity and strength, is beyond all praise, and yet were lighthouses now required to be placed in similarly exposed positions, it is more than probable that strong open-work structures, upon iron piles, would be substituted for solid stone towers, as a vast

* The discussion on this paper extended over part of three evenings; but an abstract of the whole is given consecutively.

saving would thus be effected, and the strength would be increased by removing the only cause of danger; for the waves are only formidable when they are inflexibly opposed.

In that part of the subject, which relates to foundations placed in banks of loose sand, or mud, covered by the sea, the Author would confine his observations to his own practical experience, and studiously avoid all comparison with other modes of proceeding, which he is aware may, and probably will, be brought before the Institution, and will doubtless receive the usual impartial consideration.

An account of the circumstances which led to the introduction of the screw pile and screw mooring, would possess but little general interest, and is not necessary. It will suffice to observe, that a project, contemplated by the Author, involved the necessity of a much greater holding power than was possessed by any pile, or mooring, then in use; the former being nothing more than a pointed stake of considerable size, easily either depressed in, or extracted from, the ground, and the latter a large mass of stone, or iron, which when submerged became of limited power, and was quite incapable of resisting an upward strain. The plan which appeared best adapted for obtaining a firm hold of soft ground, or sand, was to insert to a considerable distance beneath the surface, a bar of iron, (Fig. 1) having at its lower extremity a broad plate, or a disc of metal, in a spiral or helical form, on the principle of the screw, in order that it should enter the ground with facility, thrusting aside any obstacles to its descent, without materially disturbing the tex-

Fig. 1.

ture of the strata it passed through, and that it should at the same time offer an extended base, either for resisting downward pressure, or an upward strain.

Whether this broad spiral flange, or "Ground Screw," as it may be termed, be applied to the foot of a pile to support a superincumbent weight, or be employed as a mooring to resist an upward strain, its holding power entirely depends upon the area of its disc, the nature of the ground into which it is inserted, and the depth to which it is sunk beneath the surface.

The proper area of the screw should, in every case, be determined by the nature of the ground in which it is to be placed, and which must be ascertained by previous experiment. The largest size hitherto used has been 4 feet in diameter; but within certain sizes, prescribed by the facility of manufacturing them, the dimensions may be extended to meet any case, and may be said to be limited only by the power available for forcing them into the ground.

Either the screw pile, or the screw mooring can be employed in every description of ground, hard rock alone excepted: for its helical form enables it to force its way among stones, and even to thrust aside medium-sized boulders. In ports, harbours, estuaries, and roadsteads, rock is, however, seldom met with, except in detached masses, the ground being usually an accumulation of alluvial deposit, which is well adapted for the reception of such foundations, and is also that in which they are generally most required.

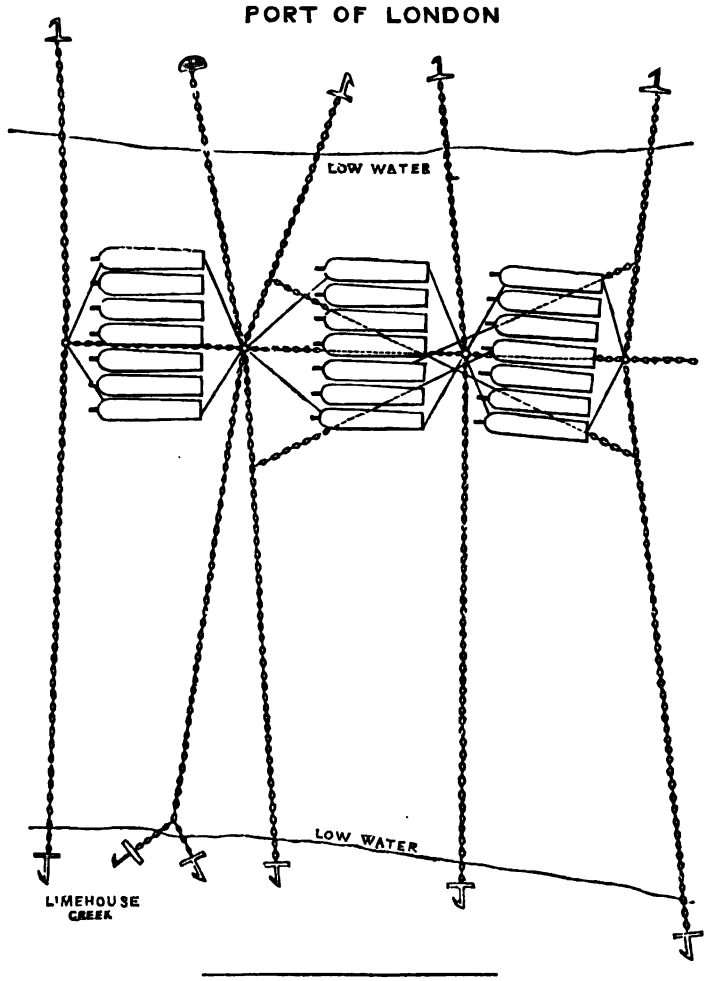
The ground screw has been already extensively used for several purposes, and its applicability to many others will be evident, from a succinct account of its present employment.

The fixed, or permanent moorings most commonly used are of two kinds; the span-chain mooring, and the sinker, or mooring-block.

The former of these (Fig. 2) consists of a strong chain of considerable length, stretched along the ground (across the river), and retained by heavy anchors, or mooring blocks, at either end, and to the middle of the ground chain the buoy chain is shackled, Many of these moorings were formerly laid down in the Thames, at great expense, and they still continue to be the only moorings in use at the Royal Dockyards. The disadvantages of these moorings are their expense and the obstruction they present to navigation; for should a vessel cast anchor in the neighbourhood, it is almost certain to get hooked into the chain, from which it can only be freed by the assistance of a chain lighter, at considerable expense and

loss of time.* In fact, mooring-chains across the anchorage were adopted to insure the anchors of vessels bringing up when the harbour was crowded, and in such cases the harbour flat is obliged

Fig. 2.

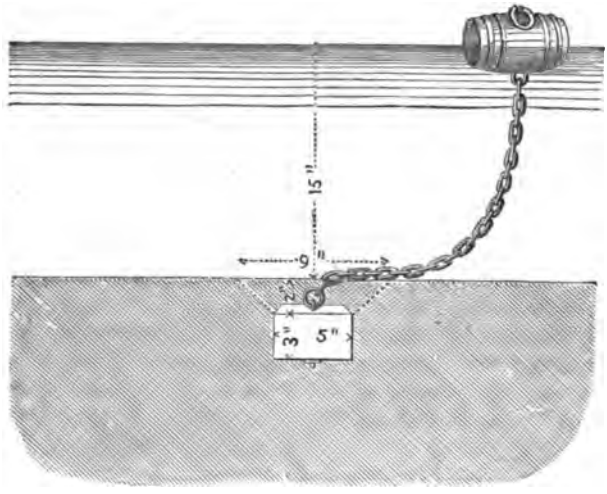


* At page 19 of Captain Denham's "Remarks and Sailing Directions for Port Fleetwood," he says, "Send your hawser to the nearest mooring buoy; trip your anchor, no fear of its hooking mooring chains, for they are Mitchell's screw moorings, and therefore grow up and down to the buoy."

to attend to clear the anchor at slack water. Messrs. Hemmans, Parkes, and others state the expense of each Government mooring of this kind to be about £2,500.

The other kind, which is more generally employed, consists of a heavy sinker, to which a strong chain is attached, extending to a buoy shackled at the other end (Fig. 3). This sinker, which is a

Fig. 3.



block of stone, or iron,* is either laid upon the surface of the ground, or is placed in an excavation prepared for its reception. The advantages of this system are its simplicity and cheapness of construction, with the power of holding nearly equally well in every direction; but, on the other hand, when the sinker is subjected to a heavy strain, it is generally found deficient in holding power, because it chiefly depends upon the specific gravity of the mass, and because the ground, which must be greatly broken up for its reception, offers only a feeble resistance to its subsequent extraction. Another disadvantage is, that being generally confined to shallow bays and harbours, vessels are often as seriously injured by grounding upon them, as when they come in contact with anchors, which it is contended should never be permitted to be used in harbours or rivers.†

* Moorings are sometimes formed of timber frames, loaded with stone and buried in the bed of the river, as in the harbour of Sunderland, where they have been extensively applied by Mr. Meik.

† "A River Steamer Sunk.—Yesterday at noon, as 'The Witch,' a steamer

These evident defects in the ordinary systems of mooring, induced the Author, whilst seeking for a simple, effective, and at the same time inexpensive mode of holding the buoy-chain down, to adopt a modification of the screw pile (Fig. 4); because it offered great facilities for entering the ground, and when arrived at the required depth, it evidently afforded greater holding power than any other form.

Fig. 4.

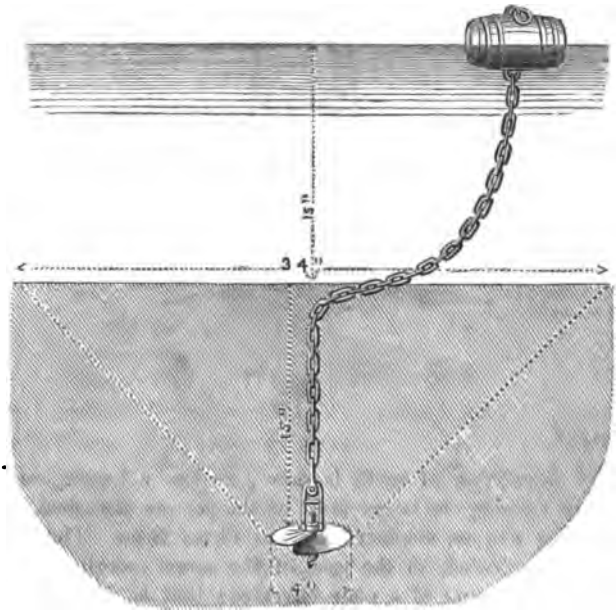
Every description of earth is more, or less adhesive, and the greater its tenacity the larger must be the portion disturbed, before the mooring can be displaced by any direct force. The mass of ground thus affected, in the case of the screw mooring, is in the form of the frustrum of a cone, inverted; that is, with its base at the surface, the breadth of the base being in proportion to the tenacity of the ground; this is pressed on by a cylinder of water equal to its diameter, the axis of which is its depth, and the water

belonging to the Old Woolwich Steam-packet Company, was on her passage to London, in standing in for East Greenwich Pier, she ran upon the anchor of a brig, of whose position the master was not aware, and sustained such injuries that she sank almost immediately. There were several passengers on board, but the tide being low the steamer was not wholly submerged at the time, though the flood tide rapidly covered her till nothing but the top of the funnel was visible."—*Vide* "The Daily News," June 6, 1848.

again bears the weight of a column of air of the diameter of the cylinder.*

It is evident, therefore, that if a cast-iron screw, of a given area, be forced into the earth to a certain depth, it must afford a firm point of attachment for a buoy-chain in every direction (Fig. 5), and will oppose a powerful resistance, even to a vertical strain, which generally proves fatal to sinker moorings, which depend chiefly on their specific gravity. The first trials were upon a comparatively small scale; but their success was so decisive, that the merits of the moorings were acknowledged, and their use soon became extended.

Fig. 5.



The depth in the ground to which these moorings have been screwed varies from 8 feet to 18 feet; the former is deep enough, where the soil is of a firm and unyielding description, and the latter depth is found to give sufficient firmness in a very weak bottom. It is evident from its form, that every part of the screw mooring is so far beneath the surface as to prevent a vessel from receiving injury from grounding immediately above it; the mooring chain

* The comparative masses of ground which must be removed in dragging up the two kinds of moorings are shown by the dotted lines in Figs. 3 and 5.

alone protruding from the ground, and it is also obvious, that anchors dropped in the neighbourhood cannot be hooked into, or get foul of the chain, one end alone being attached to the ground.

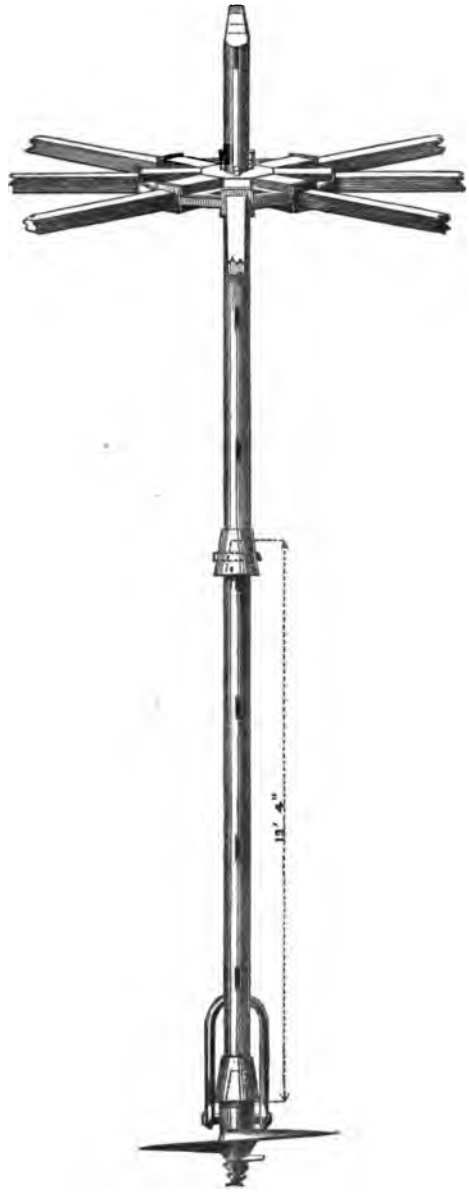
Although economy should be the last consideration, where a large amount of property and many lives are at stake, still if the end can be safely attained by less costly means, it is the duty of those having charge of public works to consider the question. It is right, therefore, to state, that screw moorings, of the most powerful description, can be put down at a tenth part of the cost of the span-chain mooring (Fig. 1), and at even less than the common stone mooring (Fig. 2), provided it be of equal power with the former; setting aside the defects which have been noticed. -Indeed, with respect to the screw moorings, it may be stated, that where they have been longest in use and are best known they are most appreciated, as is well shown in the recent agreement with the Corporation of Newcastle-on-Tyne, who paid for the permission to use the patent in the Tyne, as applied to moorings alone, the sum of two thousand five hundred pounds, within a few months of the expiration of the inventor's privilege, and when the renewal of it appeared doubtful.*

In fixing these moorings in the ports and harbours where they have been used, the persons hitherto engaged in the operation have generally been compelled to avail themselves of any means within their reach, for the construction of a floating stage, or platform, on which the men could execute the work. Barges, lighters, and pontoons, have been therefore indifferently employed; those that were without decks being planked over for the purpose. Two such vessels being lashed broadside to each other, with a certain space between them, are securely moored over the spot, and the screw mooring lowered, with the chain attached to the shackle, from the centre of the stage, to the level of the water, and as it descends to the bottom, the lengths of the apparatus for screwing it into the ground are successively attached. This apparatus (Fig. 6) consists of a strong wrought-iron shaft, in lengths of 10 feet, or 12 feet each, connected with each other by key joints, or couplings, the lower extremity having a square socket to fit the head of the centre pin, or axis, of the mooring. When the centre pin rests on the bottom, a capstan is firmly keyed upon the shaft at a convenient height; the men then ship the capstan bars, and apply their power whilst travelling round upon the stage, the capstan being lifted and again fixed as the mooring is screwed down into the ground. The operation is con-

* The patent has since been renewed for a term of fourteen years, from the year 1847.

tinued until the men can no longer move the shaft round, or until it is considered to have been forced to a sufficient depth.

Fig. 6.



In the river Tyne where (as before stated), many of these moorings have been laid down, a barge of peculiar construction has been prepared for the purpose, containing within itself all that is necessary to facilitate the work.*

The most important purpose to which the screw pile has hitherto been applied, to any considerable extent, is for forming the foundations of lighthouses, beacons, and jetties, in situations where the soil, or sand, is so loose and unstable as to be incapable of supporting any massive structure, or where the waves have so much power of undermining by their continuous action, or beat so heavily, that the stability of any mass of masonry would be seriously endangered.

Many banks off our coasts are like the Goodwin Sands, which although when dry scarcely retain the print of a horse's hoof, will, when covered by the sea, swallow up the largest ship, and are moreover in such exposed situations, that no solid structure erected upon them could resist the action of the sea for any length of time. From the number and dangerous nature of the sand banks and shoals surrounding the United Kingdom, the means of placing conspicuous and permanent marks upon them becomes an object of the highest importance to navigation; but hitherto from the difficulty of arriving at good foundations, it has been rather to be desired than expected. Beacons of a very inartificial description had indeed, at various times, been placed upon the banks at the entrance of the Thames: these consisted of old lighters, or barges, which were suffered to settle down into the sand and served as bases, on which were raised strong spars, with a ball, or other conspicuous object, at the top of each; but from the unequal washing away of the sands, they soon lost their upright position, and were ultimately prostrated. Nothing of the nature of a lighthouse upon a submarine sandbank was ever proposed prior to the year 1834, the project till then being considered extremely hazardous, if not impossible.

The Author having at that time satisfied himself as to the holding power of the screw mooring, and made some successful experiments with the screw pile, was applied to, by the Society of Merchant Venturers at Bristol, to devise the means of placing a fixed light on the Dumball, an accumulation of mud and other alluvial deposit at the entrance of the Avon, and about the end of the year 1834, he

* This barge was prepared by Mr. W. A. Brooks, M. Inst. C.E., the Engineer of the port of Newcastle-upon-Tyne, and under whose directions all these moorings were placed; but as he has promised to give a description of the apparatus, and of the moorings, it is omitted here.

laid before that Society the plan, specification, and estimate of a screw pile lighthouse, similar in principle to those since erected by him and his son; but the Corporation of the Trinity House having shortly after undertaken to buoy and light the Bristol Channel, the Author's plan was abandoned, and a stone lighthouse was placed on the firm ground in the neighbourhood.

Between the years 1834 and 1838 some unsuccessful attempts were made to introduce the plan in various localities. In the latter year, at the suggestion of Captain, now Admiral Beaufort, of the Admiralty, he laid a plan before the Corporation of the Trinity House, by whom, at the recommendation of Mr. Walker, their Engineer, it was favourably considered, and in the month of August in that year, the Author and his son laid the foundation of the Maplin Sand Lighthouse.*

Before determining the length of the piles and the area of the screws necessary to be employed, a careful examination of the ground was made, and it was proposed to use nine malleable iron piles of 5 inches diameter, and 26 feet in length, with a cast-iron screw of 4 feet diameter secured to the foot of each. Eight of the piles were placed at the angles of an octagon, and one in the centre; these were put down in nine consecutive days, being screwed into the bank to the depth of 22 feet, leaving 4 feet above the surface. The tide rises on the bank about 16 feet, and seldom leaves the surface dry.

The instrument used in trying the nature of the ground, was also employed in testing its holding power. It consisted of a jointed rod 30 feet long, and 1¼ inch in diameter, having at its foot a spiral flange of 6 inches diameter. It was moved round by means of cross levers, keyed upon the boring rod; and upon these levers, when the screw was turned to the depth of 27 feet, a few boards were laid, forming a platform sufficiently large to support twelve men. A bar was then driven into the bank at some distance, its top being brought to the same level as that of the boring-rod. Twelve men were then placed upon the platform to ascertain if their weight, together with the apparatus, in all about one ton, sufficed to depress the screw. After some time, the men were removed, and the level was again applied; but no sensible depression of the screw could be observed.

---

* A detailed account of that construction, by Mr. J. B. Redman, M. Inst. C. E., is now published, page 146, as it was previously only noticed in abstract, in the Minutes of Proceedings, when it was read before the Institution in the session of 1842.

This experiment was made in presence of Sir John Henry Pelly, the Deputy Master, and some of the Elder Brethren. The inference from it was, that if a screw of 6 inches in diameter could support one ton, one of 4 feet diameter was capable of supporting at least 64 tons, the comparative area of their surfaces being as the square of their diameters; but this experiment was nothing more than an approximation to the truth, a continuous surface possessing a much greater sustaining power than the same area in detached portions.

In fixing the foundation piles for the Maplin Sand Lighthouse, a raft of 36 feet square was used as a stage, or platform, upon which the men worked, as barges would have been too high from the surface, and it was necessary to ground the raft itself, before the piles could be screwed down to the required depth, their heads being only a short distance above the bank. The raft was constructed of balks of American timber bolted together, leaving an aperture of 2 feet in width from one side to the centre, by which the pile was brought to its position. About forty men, furnished by the Corporation of the Trinity House, were employed on the work: their wages and the cost of the raft amounted to about £300. The contract for the screw-piles, and the Author's professional charges for superintendence, was £900, making the total cost of the foundation for the lighthouse, £1200.

It would be unjust to close the notice of this work, without directing attention to the discernment and liberal spirit which induced Mr. Walker to pledge his well-earned and long-established reputation to the success of an experiment, which was certainly of considerable importance, but which was perfectly novel. The soundness of his judgment was best proved by the extraordinary stability of the structure, and the subsequent adoption of the system in other and similar situations.

Although this was the first screw-pile foundation that was laid for the reception of a lighthouse, on a bank of loose sand covered by the sea, it was not the first that was erected, as the piles remained untouched for two years, in order to ascertain if any change would occur, from the action of the sea, or other causes.

Pending this term of probation, a lighthouse was proposed to be erected in Morecombe Bay, and it was decided to use screw-piles for the foundation. The novelty of the work, the peculiarity of the situation, and the dread of failure, if it were entrusted to strangers, or to those who were not interested in it, rendered it obligatory upon the Author and his son not only to send in a design for the foundation, but also for the superstructure, and afterwards to devote their attention most assiduously to the superintendence of

the erection of the whole structure, which was commenced in the latter part of 1839, and the lantern was lighted on the 6th of June, 1840—every part, with the exception of the top of the lantern, being completed in the month of March.

As this lighthouse was the first of its kind, and it was, perhaps, the first attempt to place a habitation of any description in a position so proverbially unstable, a short description of the structure and of the locality becomes necessary.

The establishment of the town of Fleetwood was projected and commenced, by Sir Hesketh Fleetwood, lord of the manor, on a sandy rabbit warren, on which, and for a considerable distance around, the only habitation visible was the hut of the warrener; the site was, however, believed to possess considerable facilities for trade. Contiguous to, and only separated from the warren by a precipitous bank, was a deep still pool of considerable extent, where vessels of large size might be moored in perfect safety, if they could pass the barriers of shoals and banks which nearly surrounded it. Captain Denham, R.N., then Marine Surveyor of the port, had seen the design of the proposed structure for the Maplin Sands, and perceiving that such a lighthouse, judiciously placed, would render the entrance to Fleetwood Harbour at once safe and easy, he gave the matter his earnest support.*

---

* In Captain Denham's "Mersey and Dee Navigation" he thus describes the Fleetwood and Wyre seaward lighthouse, and expatiates upon its merits:—

"Description and Structure of the Wyre (seaward) Lighthouse, leading to Port Fleetwood.

"It was my study, when planning this navigation, to identify the remotest spit of bank turning into it, without subjecting the mariner to the treacherous and, at best, but partially lighting agent, a light vessel. Messrs. Alexander Mitchell and Son, of Belfast, readily took up the proposition, and the Board of Directors of the railway and harbour project as readily adopted the application of Mitchell's ingenious mooring screw to the insertion and basing of piles, or pillars, in submarine foundations. I had given much trouble to Messrs. Mitchell, when unavailingly submitting their plans and specifications to the Liverpool Dock Committee (Oct. 4, 1838), of so perfect a mode of establishing lights out upon the very banks of a navigation, whereby the power and object of a lighthouse is enhanced by proximity with the anxious observer from sea. In fact, a lighthouse can be thus erected upon any under-water spit, as indifferent to a 30-feet rise of tide and channel surge, whilst sending forth its light, of the same character and stability as if on the main land; thereby throwing it more intensely and effectively on the region required, especially where shoals outlie the main to any extent;—its time in erection the shortest possible,* and of so por-

---

* The Wyre lighthouse was reared in two of the shortest day months in the year, not affording daylight during a low water period spring tides, but depending on flambeaux, or moonlight.

The situation selected for the lighthouse (Plate 2) is about two miles from the nearest shore, on the verge of a bank of loose sand, which shifted occasionally, until it was fixed beneath and around the house by a superposed mass, several feet deep, of strong argillaceous earth and stones. It may here be remarked, that banks of pure sand are very liable to shift at their surface, and it is extremely difficult to penetrate them to any considerable depth, the absence of clay, or any plastic material, rendering the particles nearly incompressible. In this case, seven wrought-iron piles, 16 feet long, with cast-iron screws 3 feet in diameter, were employed, one being placed at

---

table a structure, that it may be removed, if local changes require, to another site in a month. Wherefore, then, should not every spit, now guarded by a light vessel, with her unavoidably inferior order of lights, rendered more so in a gale of wind by pitching, floundering about, and ever and anon being submersed in the trough of the sea, spray, and spoondrift, and that too when most wanted, and often, at the very crisis of exigency to all around, breaking adrift—wherefore not supersede them by so purpose-like a fabric? Let those who take interest, but who doubt, or cannot conceive the matter, go to Fleetwood Mount Observatory, commanding the mouth of the Wyre, and watch the effects of a westerly gale upon the first of its kind (not associating the effects of a sea-way upon the Edystone or the Bell Rock, for the screw-piled pillars do not oppose the sea); a structure destined to save many a gallant bark that would otherwise drive, unbeaconed and unwarned, upon the sands of Morecombe Bay, and I doubt not will give rise to a general adoption, whilst rendering it imperative upon local guardians of a navigation to establish refuges for the cast-away mariner on the isolated banks, since, by this method, the practicability is manifested. Indeed, this submarine method of commanding foundation and holdfast, so ingeniously contrived by Messrs. Mitchell, combines the vital essentials to the seaman's hope, of warning, guiding, succouring, and, when in port securing.

"The figure of this first screw-pile lighthouse in the United Kingdom—in the world I may say—presents to the eye a well-proportioned group of columns rising out of the sea, in the intervening and overlapping order that hexagonal or six-angled figures produce, according to the separate angles you may be opposite to; a systematic interlacing of tension-rods renders the fabric sufficiently opaque, even below the platform; but above the platform, of 27 feet in diameter, you have a six-angled dwelling-house, of 20 feet in diameter, by 9 feet high, on the centre of which rises the twelve-sided lantern, with a Chinese roof, of 10 feet diameter. Thus you have a figure of 45 feet spread at the base, contracting at the platform balcony to 27 feet, and elevated 45 feet above low-water level, surmounted, as stated, by a bulky, yet pleasing and effective superstructure, comprising a comfortable residence for the light-keepers, whilst affording you a steady, bright, and uniform light, 45 feet above the mean sea level, ranging over an eight mile horizon, visible at ten miles from a coaster's deck, and freed from those breaks of brilliancy attending the offing passage from reflector to reflector, by being fitted with a light of dioptric order. Foggy periods are provided for by a self-acting deep-sounding bell, tolling three strokes of five second intervals at one minute pauses," &c. &c.

each angle of a hexagon, and one in the centre. Seven balks of Baltic timber, 14 inches square, of the best quality, were selected for the supports of the house; the six exterior balks were each 48 feet long, and the centre one was 57 feet in length, to admit of its rising through the house to the base of the lantern, which it assists in supporting, and to give additional stability to the whole structure. In the foot of each of these supports, a hole, 5 inches in diameter, was bored, to the depth of 7 feet, to receive the end of the pile upon which it was shipped; and to strengthen them, for the same distance upwards, several strong iron hoops were driven on hot.

A small spiral flange was fixed on the foot of each balk, to draw it into the sand, in the same manner as in putting down the piles. The diameter of the hexagonal base is 50 feet, and the diameter of the platform on which the house stands is 27 feet; the exterior piles having an inclination inwards of about 1 foot in 5. It should be observed, that any degree of inclination can be given to a pile whilst it is in motion, by merely placing at a corresponding angle the platform upon which the men work. The floor of the house is 45 feet above the surface of the bank, and the tide rises about 32 feet on the supports, at the equinoxial springs.

A more detailed account of this lighthouse would be superfluous, the remainder of the work being of the ordinary character for structures of this kind; but it may be observed, that since the time of its erection in the winter of 1839 and '40, the only repair it has received, or required, is the occasional application of a little paint.

The total expense of this house was about £3,350, of which the dioptric apparatus for lighting cost nearly £1,000.

This, as before observed, being the first lighthouse placed on a bank of loose sand, covered by the sea, and from its proximity to a deep channel, entering fairly into competition with floating lights, a few words on the comparative merits of fixed and floating lights may not be out of place.

In looking out at night for narrow and intricate channels far from land, it is of the utmost importance that the mariner should rely with undoubting confidence, not only on the stability of the light; but also on its unvarying position and appearance. All these advantages are possessed by the Fleetwood lighthouse, and the others constructed on the same principle; but in tempestuous weather, the floating light ships are nearly obscured by the spray, and their lights have no steadiness, on account of the constant motion, whilst hundreds of lives and millions of property have been lost, in consequence of their breaking from their moorings. Nor can

they be said to occupy any precise position, shifting as they do with the wind and tide, twice the length of the chains by which they ride.

It is obvious, also, that the navigation is, to a certain extent, obstructed by the light-ship, which occupies the fairway channel, where it is often run against by vessels in passing; whereas, when the light is placed on the nearest bank, the passage is as clearly shown, and, at the same time, is perfectly unobstructed.

The comparative expense of these two modes of lighting remains yet to be considered; and here the advantage is still more in favour of fixed lights. The annual expense of the Fleetwood lighthouse, in lighting materials and attendance, amounts to £335, as appears by the statement of Mr. P. Bidder, resident engineer at Fleetwood, laid before the Lighthouse Committee of the House of Commons in 1845; while, on the authority of Capt. Washington, R.N., the average annual expense of the floating lights of Great Britain is £1,316. A reference to the report of that Committee augments considerably their average cost. Here then is an annual saving of about £1,000, a sum sufficient, during the eight years that the Fleetwood light has been in existence, to return twice its original cost.

In the summer of 1844, a screw-pile lighthouse, serving also as a pilot station, was placed in Belfast Lough, Carrickfergus Bay, on the tail of the Hollywood bank, about a mile from the coast of Down (Plate 2).

The depth at low water, where the house is placed, is 9 feet; the stratum, for a few feet next the surface, was coarse sand and gravel, but the soil beneath was tenacious blue clay and was easily penetrated. The cast-iron screws were 3 feet 6 inches diameter, and were used with malleable iron piles 5 inches diameter and 26 feet long, and were sunk into the bank to the depth of 16 feet.

The structure is very similar in principle to that at Fleetwood, the only difference being, that the house is larger and the lantern smaller, it being only necessary for the light to be visible from a distance of six, or seven miles.

This lighthouse, from a variety of causes, was constructed at considerably less expense than that at Fleetwood-on-Wyre. Amongst these may be mentioned the sheltered position, less costly lighting apparatus, cheap labour, and summer weather; but above all, the desire of the Author that his native town should be benefited by his labours.

Another application of the screw pile was in an attempt to place a lighthouse on the Kish bank.

This is the northern extremity of a line of sandbanks stretching from Dublin Bay to near Waterford; but separated in a few places

by openings, or swashes. It lies nearly parallel to the coast, at an average distance of between seven and ten miles from it. These banks being extremely dangerous to navigation, it was determined, if possible, to substitute two, or more screw pile lighthouses, for the feeble and uncertain guidance afforded by the floating lights.

The site first selected on account of its proximity to deep water, was, as it afterwards appeared, an unfortunate one, being a narrow tongue, or point, projecting from the northern extremity of the Kish bank.

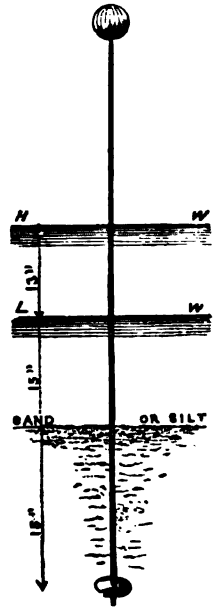
The structure was commenced in the summer of 1842, and had been proceeded with as far as putting down the nine supporting piles; but none of the angle bracing was attached; when, on the 15th of November a storm came on from the eastward, which lasted for three days, raising a tremendous sea, and removing the surface of the bank, at the spot around the piles, to a depth of 10 feet, leaving a depth of 24 feet at low water where there had previously been only 14 feet. Notwithstanding this shifting of the bank, the work would not have been disturbed, if the angle bracing had been applied; but the progress of the work had been retarded by foul weather and various unforeseen causes, and it had not been possible to take all the necessary precautions. Several of the piles were therefore laid prostrate, and the others were, after considerable abour, drawn from the bank.

This occurrence, though certainly an unfortunate one, was not, however, without its use, as it clearly pointed out, that the same skill and care which are called into requisition in ordinary structures, should not be disregarded, either in determining on fitting sites for these constructions, or in executing the works. In this instance blame cannot be attached to any individual. At the distance of eight miles from the shore, and in the absence of any fixed mark, it would have been scarcely possible, unless previously warned, to have detected, upon so narrow a surface, the change of depth that might occasionally occur.

That the principle of the screw pile has not, in consequence of this accident, suffered in the opinion of those acquainted with the circumstances, is shown by the Author and his son being at present under an engagement to examine the site of several screw-pile lighthouses, and further that three beacons have been since erected, by them, for the Dublin Ballast Board, on the Kish bank, the Arklow bank, and the Blackwater bank, which are parts of the same shoal. These have all been put down, with the intention of placing lighthouses on their sites, should they appear eventually to suffer no change by the action of the sea. All these beacons are similar in

form and principle (Fig. 7); each consisting of a single pile of wrought iron in two joints, connected by a strong screw coupling, and measuring, when together, 63 feet in length; their diameter at the surface of the ground is 8 inches, diminishing from thence both up and down.

Fig. 7.



The incompressible nature of the sand offering considerable opposition to the descent of the pile, screws of only 2 feet in diameter were used, and on the top of each pile, when fixed, a ball was placed of 3 feet 6 inches diameter. The screws used for the Blackwater and the Arklow beacons were forged of malleable iron, and turned in the lathe, at great expense; but that will probably never again be necessary, as they can generally be quite as well made of cast-iron and at much less cost.

One of these beacons was fixed in June, 1843, the other two in the summer of 1846, and are all standing, though two of them diverge considerably from the perpendicular, having been frequently struck by vessels in heavy weather.

In the summer of 1846, a larger and more important beacon was placed between the Queen's and Prince's Channels; the two most frequented passages into the Thames. It stands at the eastern extremity of the Tongue sand, in a depth, at low water, of 17 feet. The foundation is formed of five screw piles in the form of the letter X, the diagonals being 40 feet apart, one being placed at each extremity and one in the centre. These piles are of malleable iron, 6 inches in diameter and 43 feet long. Screws, 2 feet in diameter, were used, and they were sunk to the depth of 19 feet into the bank, which was very hard. The work was constructed after the design, and under the direction of Mr. Walker, C.E., and stands about 40 feet above the level of low water spring tides.

The method of putting down these piles was the same as that adopted at the Maplin sands; but, owing to the greater solidity of the ground, a raft of much greater size and strength was required, to admit of stronger apparatus being used with greater length of lever. The raft required also to be much more securely moored from its four angles, being always in deep water and in a strong tideway.

Beacons stand next in importance to lighthouses as guides through

difficult and intricate navigations, being superior in every respect to marking-buoys, however conspicuous. These latter are scarcely perceptible at night, or during fogs, and in stormy weather are frequently hid altogether, in the trough of the sea. Nor can they be considered as indicating any particular spot, shifting, as they do, for twice the length of the chain by which they ride. Should they, from accident, or age, become leaky, they sink, or, as frequently occurs, if the chain, from corrosion, or by constant attrition against the bottom, be worn through, the buoy is sent adrift.

Beacons, on the contrary, rising generally higher above the surface of the water than the eye of the observer on deck, and being backed by the sky, are in the best possible condition for being noticed at night, when they are most required, and, as they never shift their position, the seaman accords them his utmost confidence, and if they are substantially constructed, as they are not subjected to the accidents to which marking-buoys are exposed, they are calculated to endure for a great length of time.

They are usually surmounted by a large ball, exhibiting a circle from whichever side it is seen. This figure might, and has been occasionally, varied with good effect, in order to indicate the opposite sides of channels, or dangers of a peculiar description.

They can also be made serviceable as tide-gauges, showing the depth, at any given time, over shoals, or through channels.

In the summer of 1847, the screw pile was subject to a new trial, in the construction of a pier, or jetty, on the coast of Wexford; and although this work is of comparatively limited extent, yet its successful accomplishment, under circumstances of peculiar difficulty, and the important benefits to be derived from its use, give it some claim to consideration: especially as the principle is capable of extension in positions of greater difficulty, and where the advantages to be derived are more apparent and more important.

The village of Courtown is about twelve miles south of Arklow, on an open and exposed part of the coast of Wexford.

Being backed by a rich agricultural country, abounding in towns, villages, and country seats, with a numerous and orderly population, and having in front a sea abounding in fish, it was an object of importance to obtain an artificial harbour, where the surplus produce might be shipped, coals from England and Wales be discharged, and shelter be afforded to the fishing craft of the district.

With this view the late Earl of Courtown consulted several Civil Engineers; by whose advice he constructed a harbour of considerable extent, at the mouth of a small stream, and diverted into it a

second river, by a long cutting through a stratum of clay slate, hoping, by the joint power of the two streams, to scour away any sand that might accumulate at the entrance of the harbour.

To protect this work, two parallel piers were run out seawards, about 40 feet apart, with a weir and gates placed at the entrance of the dock, intending to keep the passage clear by periodical sluicings. These piers, however, only served as a trap for the sand, which is constantly shifting in large quantities along the coast. The periodical sluicings were persevered in for some time, in the hope that they would remedy the evil; but the supply of water, afforded by the rivulets, being inadequate, and no assistance being available from the tide, whose rise is there scarcely perceptible, the sluicing operation was ultimately abandoned. The place thus became, in time, in a worse condition for shipping purposes than before the commencement of the works, on which, it is said, an amount exceeding £70,000 was expended.

At the commencement of the present season of distress in Ireland, the Earl of Courtown, being anxious to aid the condition of the county, by fostering and encouraging the fisheries and the shipping trade of the neighbourhood, applied to the Board of Public Works, for counsel and assistance, in endeavouring to remedy the defects of the harbour. The Board, in consequence, despatched their engineer, Mr. Gibbons, to examine the condition of the place; but his report being unfavourable, as to the harbour itself, an extension of the southern pier was ultimately decided upon, and it being resolved to construct it as an open jetty upon screw piles, the work was entrusted to the Author and his son. After the necessary examination of the ground, a design (Plate 3), with the necessary specification in detail, was submitted to, and approved by the Board, and directions were given to proceed with the work.

On its commencement, a startling difficulty presented itself. Barges, or strongly-constructed rafts, had been previously found sufficiently steady to act as stages for the workmen, when screwing down either piles, or moorings; but the coast at Courtown being unprotected nearly from north to south, with an open sea of seventy miles in front, a surf of great height and force beats almost without intermission upon the shore, preventing the use of any floating body in the construction of the works. As a steady footing for the men is, to a certain extent, essential, it became indispensable that the screwing down of the piles should be effected from the work itself. The mode shown in Plate 4 was therefore adopted, and all interruption, or impediment, from the surf was thus avoided; whereas, had the construction been attempted from a raft, it would

have been long before it could have been accomplished, as there were scarcely six days during the season when the water was sufficiently quiet for the purpose.

The method of construction that was adopted was very cheap and simple. The piles were to be placed 17 feet apart, in a direct line outwards; a projecting stage was therefore rigged, extending that distance forwards, with the other end resting upon and temporarily attached to the solid part of the pier. The screw pile was then run forwards upon rollers, lifted by tackle, and placed vertically in the situation it was intended to occupy. A wheel, 32 feet in diameter, formed of capstan-bars lashed together at their ends, with a deeply-grooved end to each, was keyed upon the body of the pile, and an endless rope-band was passed around it, and held in tension round a smaller grooved pulley, fixed about 150 feet back towards the shore. The tendency to pull the pile out of the vertical line was resisted by a guide pole, with a grooved pulley at its extremity, which pressed against the shore side of the pile.

These preparations being made, a number of men hauling upon the endless band gave a rotary motion to the large wheel, and screwed the pile down to its place with great ease. The same operation was repeated for the next pile laterally,—the cross beams were laid on, the overhanging platform was pushed forward, and two more piles were inserted. During this time the cross braces were applied, and the permanent platform was finished.

The works were, by this means, conducted with such facility and regularity, that, in spite of rough weather, one bay of 17 feet in advance was generally completed in a day; and it is evident, that by a modification of the same system, even more could be accomplished, with greater distances between the sets of piles, if such extension should be considered necessary.

The new part of the Courtown jetty (Plate 3) is 260 feet in length, beyond the solid stone part of the old jetty. The main roadway is 18 feet 6 inches wide, with a line of railway laid upon each side, leaving a space for passengers in the centre between the lines. It is terminated by a cross head, or platform, 54 feet long by 36 feet wide, with a landing stage at each end, which can be raised, or depressed, to suit the convenience of the vessels loading, or discharging. Small colliers, coasting craft, and the largest class of fishing smacks can now receive, or discharge, their cargoes very rapidly and without grounding.

The bottom into which the piles were inserted consisted of an average depth of about 8 feet of sand and gravel, upon a firm blue clay. Screws of 2 feet diameter were therefore sufficient, with

wrought-iron piles, of 5 inches diameter, inserted in the ground to a depth varying between 11 feet and 15 feet.

The expense of the construction of the extension of this jetty, including everything, from the screw piles to the finished platform, with the lines of railway, turn-tables, landing-stages, &c., was £4150 or £47. 10*s*. per lineal yard current. In stating this sum, it must be remembered, that it was the first work of the kind; ample allowance was therefore made for contingencies, and as materials were much more expensive than at present, works of this kind could now be executed at less cost.

The distinguishing features of such piers, or jetties are, that while they are founded on extended bases, deeply and firmly imbedded in the ground, the surface that is exposed to the action of the sea is so trifling, as to offer no resistance to the free passage of the waves, which traverse without injuring the structure. From the same cause they produce no change on the surface of the ground, neither affording a receptacle for sand, and other debris which traverse their usual course, nor do they cause the smallest scour, the ordinary course of the litoral currents remaining unchanged.

The piles being of iron, are free from the attacks of the *teredo navalis*, and other marine worms, so destructive on almost every coast, and it is evident from the success at Courtown, that the same mode of construction may be adopted in works of a similar nature, but of a much more extensive description, and that the system may be safely employed in any situation, however exposed to the action of the sea, provided always that the ground be free from rock.

The success attending these applications of the system induced its extension to other works, of which it will suffice to mention a few instances, to demonstrate the large field opened for it, not only in engineering works, but for agricultural and other purposes.

Messrs. Ransomes and May (of Ipswich) have constructed several kinds of cast iron screw points, shewn in Figs. 8, 9, 10, and 11.

Fig. 8 shows the largest size, adapted for whole timber piles, which are so often splintered and shattered, and even set on fire by the rapid blows of the steam pile-driver, when traversing compact ground, and where wrought iron shoes are generally crushed into the timber, even in ordinary ground, with the force of the common pile engine. The small screw point opens the way for the conical part, and the larger screw not only draws the pile down, but, when it has penetrated to a sufficient depth, affords an extended base. Thus several feet of timber must be saved, and the general length of the pile can be reduced, as it will bear a greater

weight, and offer a more solid base when introduced to a less distance than when it rests upon the ordinary sharp wrought iron pointed shoe.

Fig. 8. Fig. 9. Fig. 10.

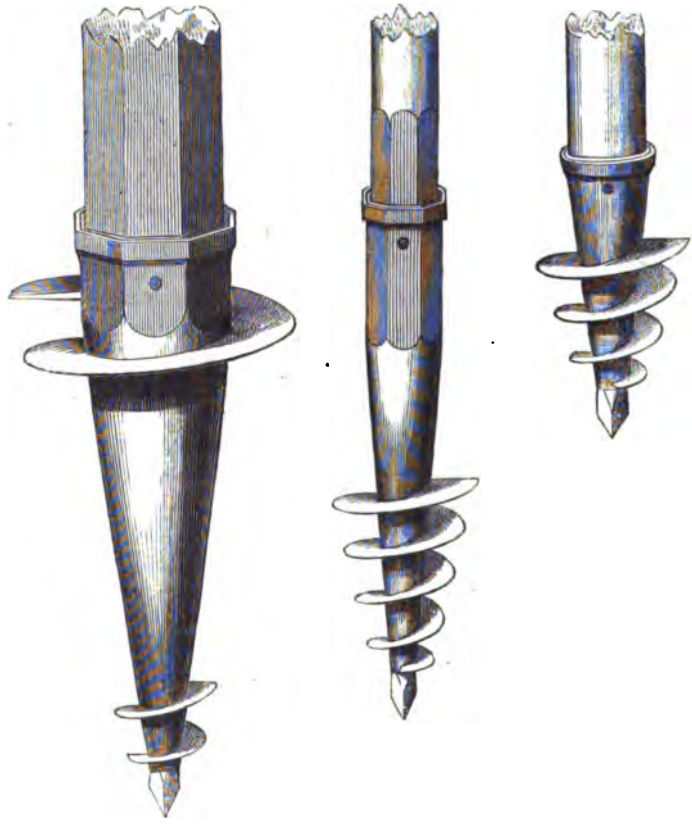


Fig. 9 shows the shape adapted for railway signal-posts, and Fig. 10 that for the supports for the wires of the electric telegraph. For these purposes the screw points must be very useful, as, independent of the economy of labour in putting them down by merely screwing them into the ground, instead of digging holes to introduce the cross feet, all possibility of injury to the banks would be precluded; whereas, at present, there is always a liability of causing a slip by disturbing uncertain ground, and admitting water in the sides of cuttings.

The cast iron screw socket points (Fig. 8) have recently been very successfully applied, for the supporting posts, or columns of

timber sheds and buildings, for railway stations and other purposes. These are generally constructed upon made ground, and the foundation for each column is prepared by excavating a hole about 6 feet deep, to be filled with concrete, which is either rammed round the post, or carries a large stone into which the column is inserted. Or sometimes by having a transverse cill and struts at the foot of the post, which must all be buried in the ground, and be liable to decay from the wet. By the system now introduced, the iron screw socket alone is inserted into the ground, by screwing it in with capstan bars; an operation which only occupies a very short time: the earth around is not disturbed, and the timber cannot be exposed to injury, or decay. The extended surface of the upper flanch of the screw affords great solidity, and the depth to which the leading screw is inserted gives an amount of steadiness which cannot be attained by any other means.

As an instance of the stability and the power of holding of these screw points, it may be stated that when trying experiments upon the various forms, Messrs. Ransomes and May screwed a casting of the form of Fig. 9 to a depth of 4 feet, into the gravel of the yard of their works, and after fixing into it a pole 38 feet in height, a man climbed to the top, and caused it to vibrate as much as possible, without apparently affecting the stability of the foot. A steelyard was then attached to it, and a power of 4 tons was applied with direct vertical tension; but without being able to draw it out of the ground, and the pole is now standing as firmly as ever. Since then, with a larger sized screw point (Fig. 8), a mast 82 feet in height, with a vane at the top 5 feet in length, has been placed, and although only inserted 5 feet into the ground, it is perfectly steady, with three very short gye-ropes.

Fig. 11 shows the applicability to smaller objects, and a tent-pin has been selected as the most familiar example, as it requires to be removed so frequently, and shows the use that may be made of the screw for the standards of fencing, and for an infinite number of agricultural and other purposes.

Fig. 11.

The originator of any plan, system, or design is, in most cases, ill qualified to judge of, or descant upon, its merits, as, with very natural partiality, he is apt to magnify its good qualities, and to endeavour to gloss over its defects; or, should he rise superior to such weakness, he seldom obtains credit for

it; this consideration suggests the propriety of refraining from further remark upon this system of construction, leaving to the Members, in the course of the discussion, to elucidate its merits, or to expose its defects. Yet, after giving this simple statement of facts, it may not be improper to observe, that persons well qualified to judge, by having carefully attended to it, have suggested the applicability of the screw pile to more extensive and much more important works than any here noticed; for example, in the construction of bridges, viaducts, and breakwaters, and even to many minor applications of apparent simplicity, but of vast extent. Should such cases hereafter arise, they may form the subject of a future paper, which the author will feel it a duty as well as a pleasure to submit to the Institution.

The paper is illustrated by four drawings, Nos. 4416 to 4420, giving the elevations, plans, and details of the lighthouses at Fleetwood-on-Wyre, and at Belfast, the jetty at Courtown, and the mode of mooring tiers of ships at Newcastle-on-Tyne, with numerous diagrams from which the Plates 2, 3, 4, and 5, and the wood-cuts, are compiled, and are presented by the Screw Pile Company.

Mr. Brooks said he had considerable experience in the use and merits of the screw moorings, and must accord them his entire approval. It was more conclusive to give facts than opinions, and therefore, although he had not come prepared to address the meeting, he would state succinctly what had been done in the Tyne.

The Corporation of Newcastle-upon Tyne had purchased for the sum of £2,500 the right of putting down screw moorings in that river, and had carried the system to a considerable extent. General benefit was experienced by the increased facilities afforded for the shipping, and on the occasion of a very heavy storm, which occurred when nearly a thousand ships were windbound in the river, and the greatest consternation prevailed, not a single mooring gave way, although they were all fearfully tried, and not £10 worth of damage was done; whilst, in the neighbouring port of Sunderland, injury was sustained by the shipping to the extent, he believed, of nearly £30,000. There were so many interesting circumstances attendant upon this occurrence, that he had caused a drawing to be made of the new method of mooring the vessels in the port of Newcastle-upon-Tyne (Plate 5), and would give a short description of it.

A heavy ground chain, composed of links each 3 feet in length, of round iron 3¼ inches in diameter, was stretched along the bed of the river in the deep water, and in the direction of the current, instead

of according to the old system, placing it as a bridle across the stream (as shown in the wood-cut, Fig. 2). To this chain, at given distances, marking the centre of each tier, and the mid-distance between, were shackled studded link mooring chains of 2¼-inch iron, which had been previously laid down, with the lower extremity of each attached to a screw mooring, inserted into the bottom of the river at each spot to depths varying from 10 feet to 20 feet.

The chain attached to the sheer screw was 2 fathoms longer than that to which the mooring screws were shackled, so as to allow the strain to come upon the mooring screws, instead of upon the sheer screws, which latter were only intended to bear the strain arising from the vessels ranging across the stream, when the wind was off either shore.

The moorings were placed where the depth varied at low water spring tides from 15 feet to 24 feet. The bed of the river consisted of sand for about 6 feet in depth, and then clay for about 4 feet; rock was generally met with, but the latter, where it consisted of a stratum of shale, was penetrated by the wrought-iron screw point, for about 1 foot, or as far as the underside of the table of the screw.

The screw moorings which were used were 4 feet in diameter, and unless they were stopped by rock, they were easily inserted to a depth of 15 feet into the sand and clay, in about an hour and a half. Some of them had been screwed down to a depth of 21 feet in less than two hours. It must be observed, however, that a very efficient apparatus was constructed expressly for the operation (Figs. 12, 13, and 14): it consisted of a hopper barge, with semi-circular leaves on each side, forming when lowered a platform of about 40 feet in diameter.

Fig. 12.

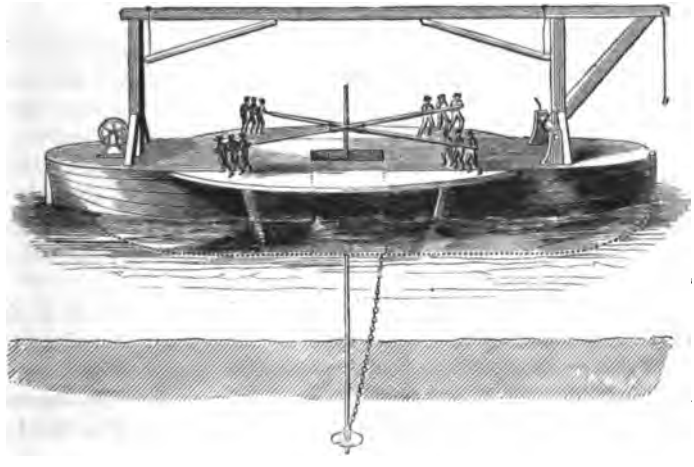
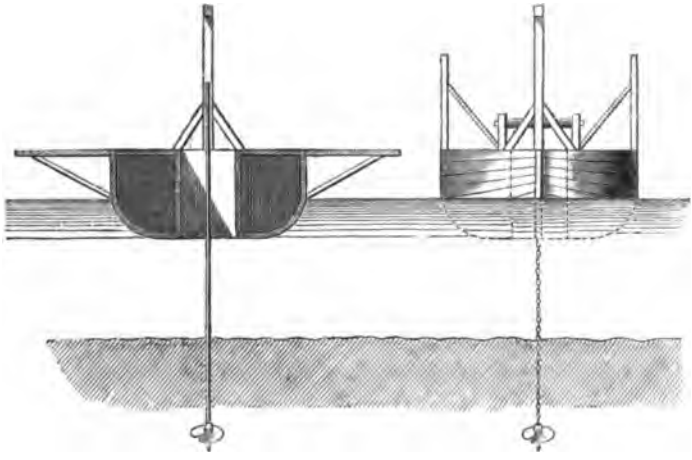


Fig. 13. Fig. 14.



The capstan had eight bars, each 20 feet in length, requiring four, or five men to each bar, according to the quality of the soil into which the screws were to be forced (Fig. 6).

Each screw was intended by Messrs. Mitchell and Son to bear a strain of four heavy ships; but during the crowded state of the port, for several months of the winter of 1847, double that number of vessels generally made fast to them.

The very great convenience of the moorings had created a general desire to make fast to them, so that their holding power was very severely tested, and they had been subjected to a strain far beyond that which they were considered capable of supporting.

By this system of mooring it was evident, that although the ground chain was continuous beneath all the tiers, yet the strain was not transferred to the upper moorings, as was the case under the old system. Moreover, it should be stated, that for several weeks (or whilst in Shields harbour alone there were nearly 800 ships lying ready to go to sea), it became necessary to moor vessels not only in the tiers, but also between each tier; thus recurring to the arrangement by which the upper tiers had thrown upon them, the weight of those below them.

Fortunately the screw moorings were able to resist even this unfair test, and no damage was done in that port, although at the same time, owing to a tier breaking adrift in the neighbouring port of Sunderland, as he had before said, damage to the shipping was stated to have occurred to the amount of £30,000. This fact had

been used as an argument for urging the more rapid completion of the docks now constructing in that port.*

With practical men, it was only necessary to allude to the difficulties of dredging in a sandy bottom, at a depth of water of three, or four fathoms, to excavate a hole, in which to sink a stone mooring, and they would at once perceive the evident facility offered by Mitchell's screws, for obtaining a much firmer mooring than by the ordinary system of sinking a stone block. So far as his own experience went, Mr. Murray considered the screws to be the best and most economical moorings that could be adopted, and so much was the port of the Tyne benefited by them, that (as had been repeatedly observed), at no former period had it been so continuously thronged with vessels of large burthen. The saving to the shipowner was considerable, because, on the first shift of wind to a point favourable for his voyage, a vessel was able to slip from the buoy moorings and be at sea in half an hour; whereas, under the system formerly followed in the Tyne (and which still existed in the whole of the neighbouring ports), a considerable degree of uncertainty existed as to effecting this object, owing to the fouling of anchors, by which the favourable opportunity of making a passage was frequently lost.

In the Tyne, within an hour of the last of the flood and the first of the ebb, or within a period of only two hours, above one hundred and fifty ships had frequently cleared out from the river, with an amount of facility and certainty which could not have been arrived at, previously to the putting down of the screw moorings.

Mr. Brooks feared that he had omitted much that was interesting in this important application of the system, and that he had not done justice to the merits of Mr. Mitchell's invention; he must, however, add his testimony as to the very liberal conduct of the Messrs. Mitchell, which alone enabled the Corporation of the port of Newcastle to use the screws upon the extensive scale which had been adopted there.

Mr. A. MITCHELL said, the system which had been devised for the Tyne, was arranged with a view of affording all possible accommodation to the vessels, and at the same time avoiding any unequal strain

* At the laying of the foundation stone of the new works at Sunderland, February 4, 1848, Mr. G. Hudson, M.P., said, "There is another disadvantage which, by the construction of this dock, we propose to remedy. Some three or five weeks ago, you had a large fleet of vessels lying here, and the damage done in one night was upwards of £10,000; and on a previous occasion, I believe, that damage was done to the amount of as much as £30,000, under similar circumstances, and we must recollect that not only is damage done but that life is endangered."—*Sunderland Herald*, February 4, 1848.

upon the moorings. In these points it had been remarkably successful, and Mr. Brooks had shown how instrumental the moorings had been in avoiding such a loss of property as had occurred in other situations, from the vessels getting adrift in heavy weather.

Mr. WALKER said, that as the paper had so fully explained the nature and the advantages of the screw moorings, it was only necessary for him to fully corroborate what had been stated; but he would add, that the principle spoke for itself, and, in his opinion, it was the best kind of mooring that had ever been employed. The Navigation Committee and the Corporation of the Trinity House agreed entirely in that opinion, respecting the screw moorings which had been laid down in the Port of London and elsewhere, within their jurisdiction.

With respect to the screw piles for foundations for lighthouses upon sand, or mud-banks, those upon the Maplin Sand had been very successful; for, although the sand on the surface had shifted considerably, being carried away and brought back again by different states of the sea, the screw piles stood perfectly; in fact, they offered no obstruction to the passage of the waves, and caused no scour.

It was seldom that an author had courage to avow a failure, and Mr. Mitchell deserved great credit for the candour he had displayed, in alluding to the attempt to construct a lighthouse on the Kish Bank; he could, however, afford to be candid, for a new invention of such importance had rarely been so uniformly successful.

With respect to the Goodwin Sands, it was not generally known, that the Corporation of the Trinity House had caused a beacon to be placed on the back of the sand, consisting of a base of cut stones well secured together, within an octagon-sided vessel, or caisson, which was towed to the spot and grounded; the sides were then unshipped, leaving the bottom under the mass of stone, and an iron beacon mast was stepped into it. This beacon was now the only one in existence upon the sands. He believed, that beacons, or other structures, erected upon screw piles, would stand as well on the Goodwin Sands as on the Maplin and other places. Schemes for lighthouses to be placed upon the Goodwin Sands were constantly pressed upon his notice; but it did not appear to be understood, that any solid edifice, to be erected in that locality, must have its foundation carried down to the chalk, to insure its durability. The Corporation of the Trinity House wished it to be understood, that it was not their intention to place lights upon the Goodwin Sands; but rather to place them around that spot, in

order that vessels might avoid its dangers. At present, floating lights were employed; but if fixed lights could be placed in the same, or equally useful localities, he had no doubt the project would be entertained. He had a good opinion of the screw piles for this purpose, and when the question came before him in a tangible form he should be ready to give it his attention, for he thought, that a lighthouse could be erected on that principle, in a difficult position, more economically than by any other plan.

Mr. Mitchell, with a very natural partiality for his own invention, thought his system superior to the Edystone and the Bell Rock structures; and other persons entertained the opinion that iron was a better material than stone for lighthouses. Mr. Walker could not however accord with these ideas. Structures of these kinds must have lasted as long, and have been exposed to a continuance of the same heavy shocks from stormy seas, as the Edystone and the Bell Rock, before the fact could be proved. The opposition offered by a solid body to the waves was used as an argument against it. It must be remembered, that the strength of a solid body was as the square of its diameter, and a structure of iron, possessing the same amount of solidity as the stone edifice, could not be contemplated. He was not aware of any instance of the destruction of a well-constructed lighthouse. The Corporation of the Trinity House was now about to test the strength of iron lighthouses, by erecting one upon the Bishop Rock, in the Scilly Islands, in a situation which was even more exposed than the Edystone. The plan adopted for fixing the foundations was, to bore holes in the rock, to clamp masses of iron into them, and then bolt down the lighthouse upon these fixed irons. Whether this system would answer, or whether stone, or iron for the structure would be the most durable, remained to be proved.

At the Point of Ayr, Mr. Walker had adopted another system for the foundation of a lighthouse placed upon piles. Cast-iron cylinders were sunk into the bank, the piles were placed within them, and each was filled with concrete; this system was practicable in certain situations, where the bank was dry at low water, but was evidently not so generally available as the screw pile, which offered great facilities, by the rapidity with which it could be inserted even at considerable depths under water, with very simple and inexpensive apparatus.*

* Mr. Brunel has recently caused a very interesting and conclusive experiment to be tried, near the proposed site of the bridge for carrying the South Wales Railway across the River Wye, at Chepstow.

A cast-iron cylinder, 3 feet diameter externally, 1½ inch in thickness, cast in

Mr. Walker could not close his remarks without saying how much Mr. Mitchell's conduct was to be eulogized, and his ingenuity and perseverance were to be admired; and when the physical obscurity under which he laboured was considered, he was entitled to more credit than would be accorded to men who could see the progress of everything around them, and were prepared to take advantage of the ideas of others in aid of their own.

Captain WELBANK, as a member of the Corporation of the Trinity House, fully corroborated Mr. Walker's statements and views relative to the screw piles and moorings. He thought the moment favourable for disabusing the public mind upon the subject of lighthouses on sandbanks; but in doing this, he did not mean to object in any way to the Maplin Sand Lighthouse, which had been so favourably mentioned, for he thought it was a very useful structure, well placed and well built.

Much had been said lately about caissons, beacons, and lighthouses on the Goodwin Sands; now he was of opinion, that a lighthouse upon a sandbank could never mark the extreme danger; but that floating lights, moored in deep water beyond the spots of danger, might be approached with confidence, and were on that account preferable to fixed lights on sands, the distance of which from the eye could not be accurately judged of, particularly in tempestuous weather and in circumstances of danger.

---

lengths 10 feet each, with internal socket and joggle joints, secured with pins and run with lead, was armed at the extreme bottom with a sharp wrought-iron hoop, and a little above it was a helical flanch projecting 12 inches all round from the body of the cylinder, around which it made an entire revolution, with a pitch of 7 inches. By means of capstan-bars worked by manual labour, and by strong winches, this cylinder was screwed into the ground, near the bank of the river, but out of the influence of the tide, to a depth of 58 feet, in 48 hours and 14 minutes, through stiff clay and sand down to the marl rock. In descending to that depth the cylinder made one hundred and forty-two revolutions, and the average rate of sinking per revolution, very nearly accorded with the pitch of the screw. The time quoted is only that which was actually consumed in forcing the cylinder down, as it was allowed to rest for long periods, whilst the interior core of clay was repeatedly cleared out, and on account of the breakages of the ropes, and the capstan-bars, and other casualties incidental to all first experiments. In spite of the great surface exposed to lateral friction, the cylinder was always started again with comparative ease, and its progress downwards was very uniform.

It is the intention of Mr. Brunel to try a cylinder 6 feet diameter, with a larger helical flanch, or screw, before deciding upon the dimensions of the cylinders for the foundations of his bridges, to be placed in situations where there is a great depth of mud, stiff clay, and sand. Of this and the subsequent experiments, accounts may probably be given hereafter, by Mr. Brunel's permission. August, 1848.

Buoys partook of the character of floating lights, and, when they were properly constructed, of considerable dimensions, rising well out of the water, and securely moored by Mitchell's screws, or other effective means, he considered they were better than beacons and were a greater security for the navigation.

It had been stated, that the light-ships were in the habit of parting their moorings: this assertion was not correct, as a general statement, and it had arisen from some accidents which occurred a few years ago from the use of some chain cables of inferior quality, which bore perfectly the ordinary steady strain in the proving machine, but broke when they were subjected to the jerk of the sea upon them when in tension. All the chain cables used by the Trinity Board were now tried by hammering the links under tension, and since that plan had been adopted no accidents had occurred from the parting of cables.*

---

* In a letter, dated February 29th, 1848, addressed to the Secretary of the Institution, Captain Washington, R.N., says, "It has fallen to my lot, in visiting all the harbours in Scotland and Ireland, and great part of those in England, to have seen and examined the screw-pile lighthouses on the Maplin Sand, at the entrance of Fleetwood, and at Belfast, and I can bear the fullest testimony as to their utility and their stability.

"I have also seen the screw moorings laid down in the Clyde, both at Glasgow and at Greenock, in the Humber and in the Tyne, and in all places have heard them well spoken of; those in the Tyne, I have reason to believe, have already saved some thousand pounds' worth of shipping from damage. As a sailor, fully alive to the value of good ground tackle, I strongly recommend their use in all harbours in which space is an object—and in what harbour, or river is it not?

"I see in the report of the meeting it was stated, that 'floating lights were preferable to fixed lights.' If such was said, with all deference I must beg to differ from such doctrine.

"In spite of all the efforts of the Trinity Board to provide their floating light vessels with the very best chain cables, to moor them in the securest manner, to have the vessels built in the easiest form for riding in a heavy sea, and notwithstanding their liberal (I might almost say lavish) expenditure, to secure these very desirable results, I have known three of these light vessels break adrift, in less than two years, in the North Sea—the Gallopers, the Leman and Ower, and the Shipwash (I think). I admit the vessels were replaced as speedily as possible, that is, in a few days after the gale was over; but in the meanwhile what becomes of shipping, boldly steering for a light that marks a sand, and only discovering that it had broken adrift by finding herself high and dry on a shoal?

"I admit there may be exceptions, as at the Goodwin Sands; but the exception only proves the truth of the rule.

"Another point, although in my opinion a very minor point when the lives of our seamen are in danger, is the difference of expense. I happen to have before me the Report of the Select Committee of the House of Commons on

Mr. MITCHELL begged to thank Mr. Walker, not only for the handsome manner in which he had mentioned him individually, but for the kind and candid testimony he had given in favour of a system, to the perfecting of which, many years of anxious labour had been devoted; but for which, he eventually hoped to be rewarded, when the members of the Institution were aware of what had been already executed, and to what a variety of engineering constructions the screw pile and moorings could be advantageously applied.

It must not, however, be supposed, that in mentioning the Edystone and the Bell Rock lighthouses, he meant to even insinuate anything against the merit of these structures, which no one could admire more than he did, and no one could more reverence the talent of the designers and constructors; nor did he mean to assert, that iron was preferable to stone. He only alluded to the question of relative expense, which was in favour of iron, where it could be advantageously applied. He had however heard, that in the Edystone lighthouse, during heavy storms, the vibration was so great, that the rate of going of the time-pieces was affected. Now, at the Fleetwood lighthouse, even during the heaviest weather, there was so little vibration, that the time-pieces were never affected.* If,

---

Lighthouses in 1834, which gives the comparative expense of fixed and floating lights in Ireland. In the Appendix, (p. 145), it will be seen, that the first-class fixed lights, with twenty burners each (say the Skelligs), cost annually £508. 10*s.* for maintenance, whereas the average of the cost of the Arklow and Kish floating lights exceeds £1,000 a-year, or double that of the former.

"But if we take the average of all the fixed lights in Ireland, the annual cost is only £353 each, or nearly one-third of the Kish light-ship, which in the year cost £1085. 11*s.* 2*d.*

"Of the inefficiency of light-ships in heavy weather, at the very time they are most wanted, I need only adduce one instance. In talking to the Master of a Cork and Bristol steamer, about the Salter's light-vessel, off the south-east coast of Ireland, he replied, 'Lord bless you, Sir, we never see her till we are a-top of her.' After this I trust we shall hear no more of floating light-vessels, in preference to fixed lights, wherever a good submarine foundation can be established; and this, I believe, Mitchell's screw-pile has shown us how to obtain."

* In a letter dated March 24th, 1848, addressed to the Secretary of the Institution, Lieutenant Frederick Robinson, R.N., says, "During the time I was on the survey under the command of Captain H. Mangles Denham, I passed three days and nights, at three several periods, in the lighthouse erected at the foot of the Wyre, during heavy gales of wind, for the purpose of satisfying myself as to the maximum of oscillation, and although a small hoop and plumb-line were used, so little was the deviation from the perpendicular that it was not worthy of observation. It was, however, noticed that in heavy squalls there was an inclination to leeward; this continued during the squall, but the perpendicular was perfectly resumed in the lull, easily and without any jerk.

"The Wyre lighthouse was the wonder and admiration of every naval man who visited it during our stay on that coast."

then, vibration was any evidence of weakness, as the absence of it indicated stability, a screw-pile lighthouse, which offered no opposition to the waves, was less liable to injury, than a more solid edifice.

With respect to the floating lights, he must be permitted to express surprise at their being continued, wherever it was practicable to place a fixed light, as the annual expense of the latter was about one-third that of the former, and he had never yet heard of a spot, where a floating light was considered necessary, in which he could not place the screw piles, for the foundations of a permanent structure. They were generally required in shoal water, to mark dangerous spots; but he should have no hesitation in placing screw-piles in depths of water of five or six fathoms, and would guarantee their success.

Mr. MURRAY said, that some years since, he had tried two of Mitchell's small moorings, 2 feet diameter, screwed into the strata above the magnesian limestone. As they were tried early in the introduction of the invention, he used them only as shore moorings; after some time, having made some alteration in the works, which induced changes in the river, the bottom was dredged up and the screws were found broken across their centres. This, he thought, might be attributed either to an original defect in the castings, before the founders were accustomed to their manufacture, or to their being made too thin. If the substance of the metal had been better proportioned, he was convinced they would not have failed, and he did not adduce this circumstance as detrimental to the reputation of the moorings; but in order to state the actual facts of the case. He should, probably, have employed them more extensively at Sunderland, only he was not quite certain of the locality being adapted for them, on account of the comparatively small depth down to the limestone. He thought they were very valuable, not only from their strength when once screwed down; but from the facility with which they could be fixed in any strata, except rock. They had been screwed down easily 15 feet into sand, in an hour and a half, whereas he had never been able, by the use of either heavy or light, pile engines, to drive piles even 12 feet into sand, without shattering the heads. He believed, that the screws could be put 30 feet down into sand, or shingle, without much difficulty. This was of the utmost importance in submarine foundations, on exposed sand and mud-banks, where the material was liable to shift, and where, unless the foundation was carried to considerable depth, the stability of the structure would be endangered.

Mr. RENNIE confirmed all that had been previously stated, as to the applicability and the efficiency of the screw piles. He had

constructed many of them for Mr. Mitchell, and felt convinced of the advantages they possessed, not only for structures like that of the Maplin Sand, but for any foundations of a treacherous nature, or where it was desirable to offer very little resistance to the action of the sea, and to permit the free passage of the sand and shingle. It was evident, that these piles possessed great solidity, as the stability and power of sustaining a superposed weight, and of resisting extraction, must be directly as the area of the surface of the screw, plus the depth to which it was inserted, and when, in addition to this, the facility with which the pile, or the mooring could be put down, was considered, he knew nothing that offered similar advantages.

Captain Moorsom was particularly struck with the simplicity of the construction of the Courtown pier, the facility with which it appeared to have been erected, and its moderate cost, under somewhat disadvantageous circumstances. Of course, then, it was fair to infer, that in ordinary cases, where such a structure would be required, it would be even less expensive, and then it must be evident, that no solid building, or even mass of rubble-stone, could compete with a structure placed upon screw piles. It had been stated, that the terms hitherto demanded for the use of the screw piles had somewhat limited their employment. This was to be regretted, because they were such useful implements for enabling engineers to overcome difficulties, that in the interest of the profession, they should be rendered accessible to every one who had works to execute in any indifferent, or bad ground. For piers of bridges and viaducts they were, from their stability, infinitely superior to common piles, and if used with judgment they might be rendered subservient to economy.

Mr. A. Mitchell explained, that peculiar difficulties had existed, which had enhanced the cost of the Courtown pier. There was a heavy surf setting upon the shore, and a new system of putting down the screw from the pier itself, required to be designed and provided for; therefore a larger price was demanded, to cover this and other contingencies than would at present be required for similar works. It was right also to mention, that the first few piles had to penetrate a mass of rubble-stones, that had been thrown down to protect the foot of the foundations of the stone pier. The screws appeared to turn aside these stones, and to descend vertically without any difficulty.

Mr. Scott Russell suggested the applicability of the screw piles for forming an open breakwater. He thought, that a structure might be designed, which should so break up the waves, without opposing any positive resistance to them, as to obtain nearly still water on the lee side, and at the same time be itself quite safe from

destruction. The subject was well worth general attention by engineers.

Mr. WALKER thought the discussion of the applicability of the screw pile and moorings to open-work breakwaters, should be adjourned, until the Institution should have presented to it an account of one of those structures.

There could not be any doubt of the holding power of the mooring screws. Mr. Walker had recently had a long conversation with Mr. Smith, one of the Elder Brethren of the Trinity House, at Newcastle-on-Tyne, and who, from his position as pilot-master at Shields, was a very competent judge of the merits of the screw moorings. He had given the details of the position of the vessels in the Tyne, described by Mr. Brooks, and agreed with him in attributing the general safety of the tiers of vessels, and the absence of injury, on the particular occasion of the storm in question, to the holding powers of the screws, which were, however, tried much beyond the legitimate intent. He further stated, that if, under the circumstances of such undue strain, they had failed, he should not have had less confidence in them for ordinary purposes, or when their powers were not unduly taxed. From all he had seen, he was convinced they were far superior to every other kind of mooring, and he thought the River Commissioners of Newcastle had conferred a great benefit upon the shipping interest, by providing such efficient moorings. Mr. Smith had known the port of Shields for sixty years, and never remembered to have seen it so encumbered with shipping as on the occasion to which he alluded.*

Mr. Walker fully accorded with Mr. Smith's opinion, and he hoped that the introduction of both the screw piles and the screw moorings would become general. They would have been more employed, but for the high terms demanded for the right of using them. This had driven Mr. Walker to devise a plan which he had used with success in the construction of the lighthouse at the Point of Ayr, where he should certainly have used the screw piles if he could have agreed with Mr. Mitchell as

* In a letter to the Secretary, dated March 4th, 1848, Mr. Smith says, "The Harbour Masters, with whom I was in communication relative to the alarming situation of the ships during the tremendous pressure from the crowded state of the Tyne, at the period of the heavy gale alluded to, concur in stating, that the screw moorings were perfectly equal to the undue strain imposed upon them, and that they bore the severe trial excellently. I am of opinion, that with care in selecting the proper situation for putting down the screws, and perhaps combining with them dolphins, for the head and stern ropes, under certain circumstances, no other mode of mooring can be adopted, which offers so much security for the tiers of shipping."

to price. Mr. Mitchell had now disposed of his invention to some men of business, who, he was sure, would understand their own interests too well, not to bring the terms within the reach of every application.

Mr. CUBITT, *V.P.*, could only offer an opinion on the evident value of the screw piles, as hitherto he had no actual experience in using them; but he was well aware of the various structures to which they had been applied, and thought there were numerous adaptations of them, both for permanent and temporary constructions, in which they would be found extremely useful. They had been found essentially serviceable in shoring up a large stone construction, when delay in affording support to it might have proved very prejudicial, and where the vibration caused by any attempt to drive piles would certainly have produced the ruin that was sought to be prevented; the screw piles were, however, put down very quickly, without causing any vibration, and the centres were packed up on them. Mr. Cubitt intended to use the screw piles for supporting the temporary stages for erecting some wrought-iron tubular beams, for a railway bridge of large span, and he was sure the contractors would find them very useful, as well as economical, for that kind of work, as when the structure was completed, the screw piles could be taken up, and could be used again for similar, or other purposes. He intended also to use them for mooring the large landing stage in the Mersey, at Liverpool. The manner in which Mr. Mitchell had hitherto applied both the piles and the moorings, was very creditable to his ingenuity; and Mr. Cubitt hoped to see them very generally used, as he entertained the most favourable opinion of them.

Mr. CLARKE inquired, what was the greatest depth to which Mr. Mitchell had yet found it practicable, or rather to which it had been necessary to put down the screw piles, particularly in an average stiff clay? He was aware, that these piles had been employed for supporting a considerable stone structure, and he thought there were many situations in which they would be very useful for forming the main points of coffer-dams, where the screws and the lower part of the pile could be left in the ground after the construction was finished, only unshipping the upper part; as there were instances of the stability of works being injured by the piles of the coffer-dam being drawn. Mr. Clarke had great confidence in the screw pile, for many purposes, and, as a contractor, he thought it could be rendered extensively useful.

Mr. MITCHELL replied, that he had put screws of 4 feet diameter 26 feet deep into clay and sand, and could have forced them

SUBMARI[illegible]OD ON WYRE.

LIGHTHOUSES EREC[illegible]

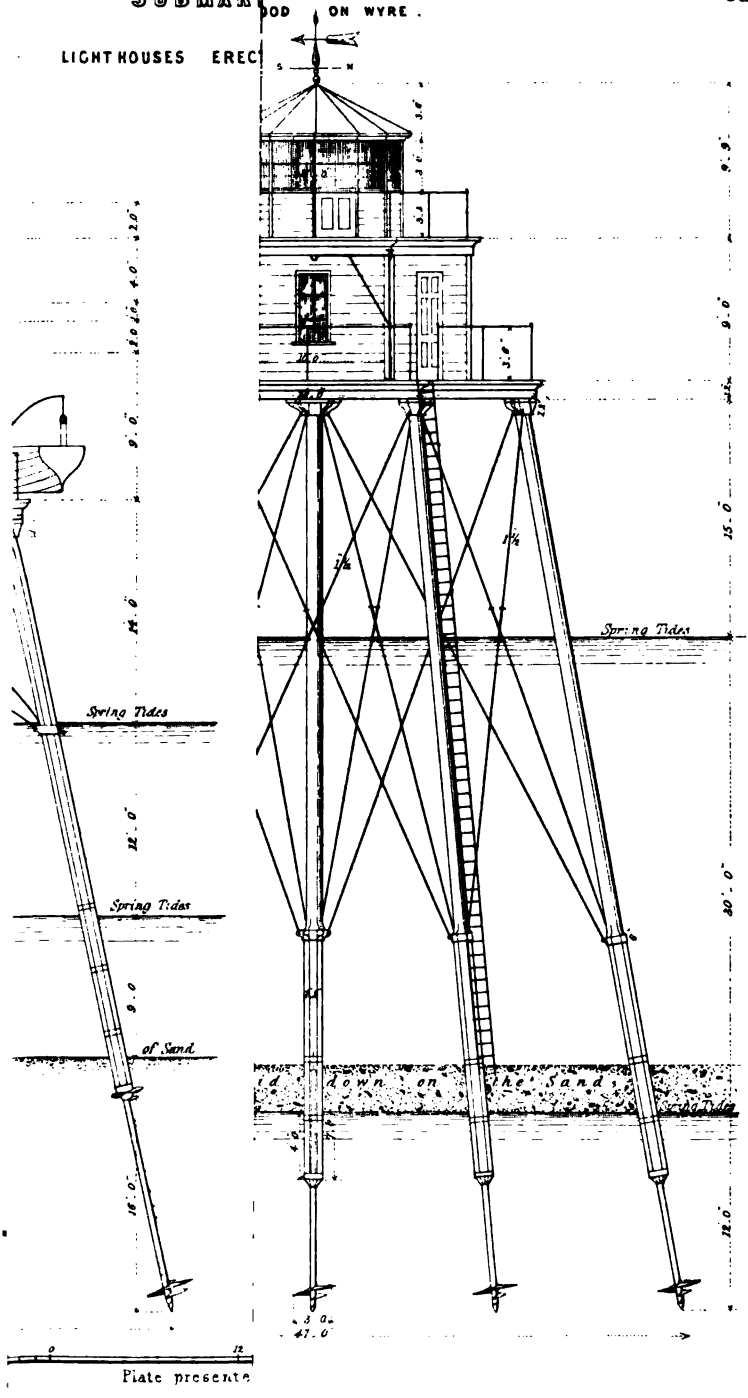


Plate presente[illegible]

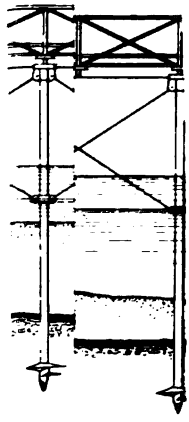
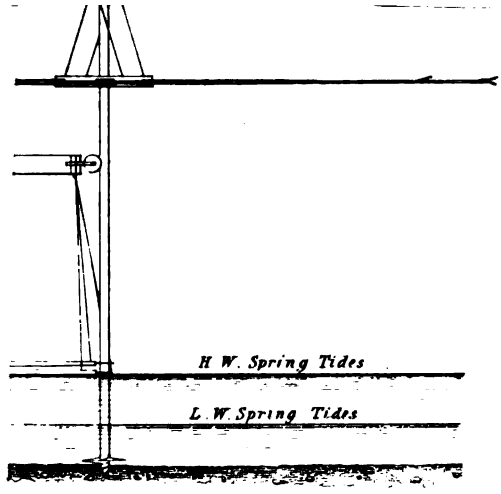
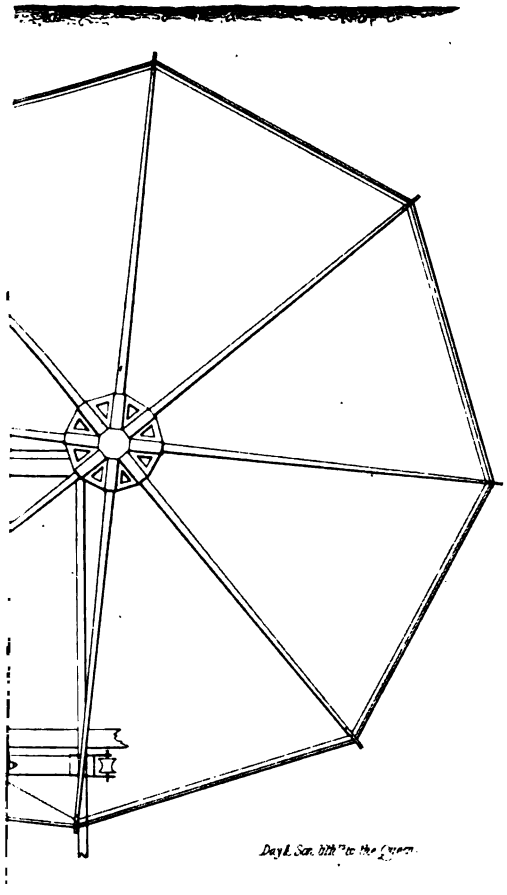
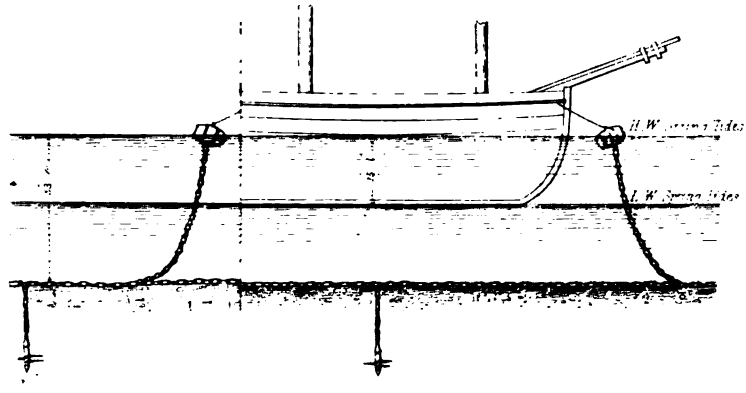


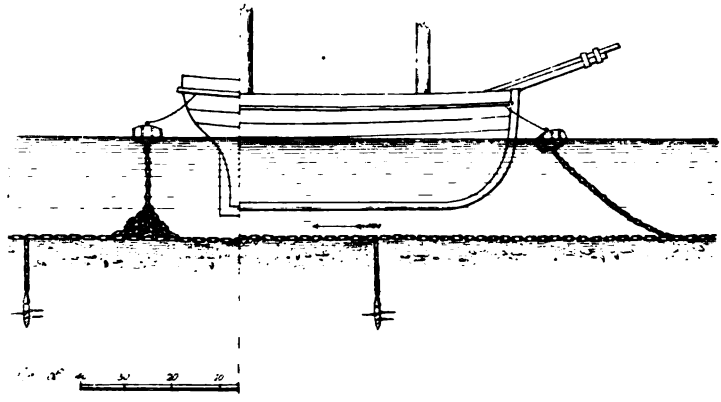
Fig. 6.

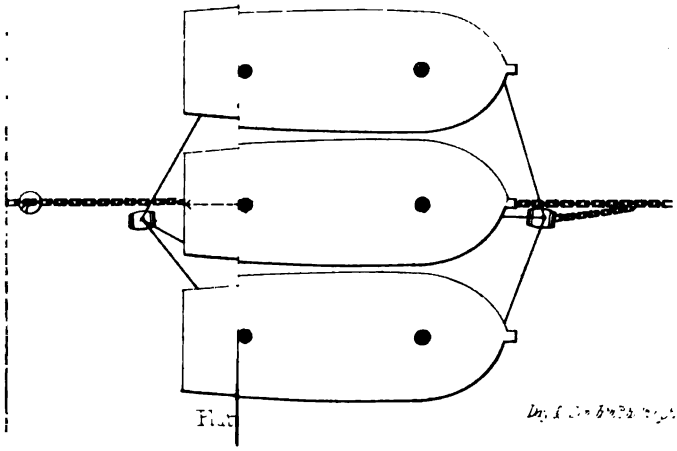

H W. Spring Tides
L W. Spring Tides



F MOORING VESSE







down still further, by extra power; but it was not necessary. The screw traversed clay more easily than almost any other strata. Sand was more difficult to penetrate,* and when there were many stones, they sometimes caused trouble; but hitherto the proceedings have never been effectually stopped by anything except rock. He believed, that by a slight modification of the screw, it would be enabled to penetrate soft chalk, and would find excellent holding in it. For the Tongue Sand beacon, a wrought iron pile, with a screw of considerable area, had been put down 19 feet into the sand, without any difficulty.

Mr. Mitchell was aware, that hitherto he had perhaps demanded too high terms for the right of using the screw piles and moorings; but it must be remembered, that he had to serve an apprenticeship in the matter, and that he feared to intrust to other persons the power of using them, lest they should misapply them, and injure their reputation. This caution had, no doubt, been prejudicial to him, in a pecuniary point of view, and had retarded their general introduction; but still he almost preferred that result, as he could look back

---

* In a letter to Mr. Mitchell, dated March 26, 1848, Colonel Underwood, H.E.I.C.'s Engineers, says, "I was much pleased to see Mr. Walker rise at the Institution to do you justice, and to bear his valuable testimony to the merits of the screw pile. I was anxious to state one particular relative to the screw pile, which has not, I believe, been alluded to; this was its most valuable and almost inappreciable quality for aiding in driving piles into a compact sand. The coast of Coromandel is composed of such fine compact grained sand, that all efforts to drive piles with the common monkey are almost unavailing. In the years 1838 and 1839 I had to throw out a series of groynes, to protect a portion of the coast, which the encroachment of the sea was undermining to such an extent, as to endanger some valuable Government property. The operation of driving our piles was attended with the greatest difficulty and loss. These piles were composed of a very tough strong wood, well pointed and armed with iron; heavy monkeys, our only resource, were used to drive them; but we could not succeed in getting them deeper than five, or six feet, with all the power we could bring upon them, and a great number were snapped off in driving, from the recoil occasioned by the elasticity and the compact nature of the sand through which they were driven.

"During the period of my holding the situation of superintending engineer of the Presidency division at Madras (upwards of eight years), many instances occurred of these difficulties, all of which would have been obviated had we been in possession of your admirable and simple invention of the screw. I am now more than ever convinced of its utility, and I may say necessity, for all works where pile-driving may be resorted to, in operations on the Coromandel coast of India. Your kindness in allowing me to be a witness to your works at Courtown harbour, gave me an opportunity of observing how simply and easily the operation of getting piles down in deep water, may be effected by means of the screw."

with confidence upon almost every work he had executed. Now, however, he had become bolder, and as he heard the general expression of opinion of the members, in favour of both the piles and the moorings, and their determination to employ them, he should feel perfect confidence in their skill, in adapting them to the numerous uses of which they were susceptible, and if, for fear of prolixity, he had not given in the Paper ample directions for executing the various works, he would, with permission, supply the omissions before it was published, and would give to the members any further information in his power, which was the least return he could make for the valuable suggestions that had been offered publicly, in the course of the discussion, and privately by almost all the eminent Engineers and Contractors whose attention had been directed to the subject.

No. 525.—"An account of the Maplin Sand Lighthouse, at the mouth of the River Thames."* By John Baldry Redman, M. Inst. C. E.

The mouth of the River Thames is intersected by numerous sand-banks, at its junction with the ocean; the principal entrances are, the Swin, or King's Channel, on the north, and the Prince's, Queen's, and South Channels, on the south side; the sands which separate these main channels are the East and West Barrows, Nob, Knock John, Sunk, Girdler, and Long Sands.

The Swin, or King's Channel, is probably the most frequented, though not by first-class ships; but all east-country craft, and the greater portion of the coasting and collier vessels pass through this channel; in fact, the traffic appears almost continuous, for in fine weather there is a complete succession of ships to the east and the west as far as the eye can reach.

This channel runs between the Maplin sand on the north, and the Mouse, and the East and West Barrows' sands, on the south; at the western extremity of the Mouse sand, the channel is marked by a floating light of that name; from this light downwards, the channel bears N.E. by E. to the southern point of the Maplin sand, which is about three miles below the Mouse light: the channel then takes a N.E. direction, and five miles below the Maplin lighthouse,

---

* This paper was read at the meeting of May 24, 1842, and a short abstract of it was published in the Minutes of Proceedings of that year (Page 150); but as it is particularly alluded to by Mr. Mitchell in the paper "On Submarine Foundations" (Page 118), it is printed at length, with the discussion upon it.

is situated the Swin Middle light, marking the extent of the western end of the Middle and Heaps sand, which forms the southern boundary to the outlet of the channel, running between the Swin Middle light and the Whittaker beacon, at the north-eastern extremity of the Maplin sand: this light also points out the entrance to the Burnham river. The Swin channel, at its junction with the ocean, takes nearly an easterly direction, running between the Gunfleet sand on the north, and the Middle and Heaps to the south. Thirteen miles to the eastward of the Swin Middle light, is situated the Sunk light, which marks the northern spit of the sand of that name, and is the southern boundary to the entrance common to the Swin and the Barrow-deeps channels.

From this sketch of the intricacies of the Swin channel, it will be evident how important it is, to keep up an efficient system of lighting in so frequented a passage.

The Mouse light of the Swin channel is about fifteen miles distant from Southend, and about twelve miles from the Nore light, which latter is situated at the eastern extremity of the Nore sand, and marks the entrance to the southern channels, between the Nore and the Warp sands.

To the south of the point of the Maplin sands, where the lighthouse now stands, the channel was formerly marked by a floating light, called the Sheers. In light vessels, the lantern encircles and slides upon the mast, and is raised and lowered by a crab and chain, and these vessels are rendered more conspicuous during the day by being painted of a bright red colour; and a globe, about six feet in diameter, formed of thin wooden ribs, connected together by belts of the same material, is placed at the top of the mast.

The Swin Middle light vessel differs from the others, as the lantern revolves round the mast, being worked by machinery, which is wound up every two hours. The establishment in these vessels consists of six, or seven men, who are relieved every two months. The light vessels afford a good light by night, and are floating beacons by day; but are liable to drift from their moorings, or to suffer damage from vessels running foul of them, as they are generally in the fairway of the channel. In the event of their breaking from their moorings, serious calamities are liable to occur to shipping,* and

* During the gales of the winter of 1841, the danger to which vessels are exposed in the event of floating lights drifting from their moorings, was most fatally and fearfully proved; for on the night of Sunday, 22nd November, the Brig "Mary," of North Shields, and seven others, were wrecked on the Sunk sand. They left Orfordness with a strong gale from the N.E., running for the Swin channel, being confident of making the Sunk light-vessel at the entrance

the expense of maintaining them is also a serious objection to floating lights.

The Sheers light was, from its situation, one of the most important in the Swin, or King's Channel, as it marked the south-eastern extremity of that large flat, called the Maplin sand, and consequently pointed out the bend in the channel; the establishment of a fixed light on the point of this sand was therefore considered a very desirable object by the Corporation of the Trinity House.

A deputation of the Elder Brethren of the Trinity House, accompanied by Mr. Walker, their Engineer, visited the spot in 1837, for the purpose of surveying the sand, and of ascertaining the best position for a fixed light; various soundings were taken at the time, and the observations were extended to the eastward, as far as the Sheers beacon, which is situated 40 fathoms N.E. of the spot chosen for the new building. This beacon served formerly to mark the southern extremity of the sand, which however growing out, or increasing, to the westward, was rendered comparatively of little use. At low water the stump of an old beacon, the predecessor of the present one, may be seen about 50 fathoms still farther to the eastward.

From these facts, the sand would appear to have extended gradually to the westward, supposing that these beacons, when erected, were so placed as to mark the full projection of the sand.

A boring was made, during this survey, at the south-eastern point of the sand, in order to ascertain its nature and density: this was carried down 27 feet below the surface of the sand, or 26 feet below low water. The sand was compact and hard, so that with an ordinary boring-rod, worked by four men, a depth of 6 feet was penetrated in half an hour, and beneath that depth the facility increased, as the sand appeared to become mingled with silt.

The sand, at the time of the survey, was, at the spot chosen for the lighthouse, from 12 inches to 18 inches above the level of low water spring tides, which here rise 15 feet, and it is high water at

---

of the channel; but, unfortunately, in the gale that raged during the previous night, she had drifted from her moorings, and had thus become useless, not daring to show her lights; the consequence was, that all these ill-fated vessels ran on to the Sunk sand in a fearful sea; one of them, a schooner, went to pieces in a few minutes, and all hands perished; a similar fate attended all on board of the "Mary," except the Captain, who swam to one of the other vessels, the crew of which was picked up the next morning by some fishing vessels from the rigging, where the men had remained all night. The whole of the vessels were completely wrecked.

those periods between 12 and 1 o'clock: the rise of neap tides is 9 feet. The set of the flood tide, to the south of the sand, is from E.N.E. to W.S.W., and of ebb tides west to east. At Sheerness, which is 20 miles higher up the river, the rise of the spring tides is 17 feet 6 inches, and of neap tides 11 feet; there is, therefore, a difference of from 2 feet to 3 feet in the rise of tide between the two places.

Soon after this preliminary survey, Mr. Mitchell, the inventor of the screw moorings, made an application to the Corporation of the Trinity House, that in the erection of the proposed lighthouse on the Maplin Sand, his screws might be used for the foundations; suggesting that the screws should offer considerable bearing-surface, and be fixed upon the ends of wrought-iron piles, which would support the superstructure. This suggestion was favourably received, and in June, 1838, Mr. Mitchell received instructions to supply the screw piles, and to consult with Mr. Walker as to future measures.

On the 27th August, Mr. Mitchell and his son proceeded to the sand with the piles, which were manufactured of the best Staffordshire iron, 26 feet in length, and 5 inches in diameter; each pile had near its lower end a cast-iron screw, 4 feet in diameter, firmly keyed upon the pile, round which the screw performed one revolution and a quarter; beneath the screws the piles were finished with a large drill, or opening bit. The screws were manufactured at Messrs. Rennie's works, Holland-street, Blackfriars.

One pile was placed at each point of an octagon, with one in the centre, and they were screwed down into the sand in the following manner:—A raft, about 30 feet square, had been previously prepared, with a longitudinal opening from one side to the centre, for the admission of the pile; this was towed over the spot where a pile was to be screwed down, and was held in its proper position by means of warps, the pile being pitched upright, and projecting through the opening left for that purpose; a capstan head was then keyed on to the pile at the proper level, the bars were introduced, and by manual labour the piles were screwed down, the capstan-head being shifted up as the piles descended.

The first pile was screwed down on the 28th August, and all the nine piles were finished on the 5th September, the average work being one pile per day.

The labour required for screwing the piles down varied so much, that Mr. Mitchell appeared to think the ground was rather unequal; but, for the most part, the sand appeared to be clean and firm for about the first 8 feet, and then became looser for about 3 feet,

the rest being generally uniform; and Mr. Mitchell believed it was slightly mixed with an argillaceous earth, particularly for about 2 feet towards the greatest depth.

The piles were screwed down 21 feet below low water (Fig. 1, Plate 6), their tops being 5 feet above that level, and from 4 feet to 4 feet 4 inches above the sand. In a few tides the sand was found to be considerably lower at the S.E., being 6 feet below the pile heads, whilst at the northward it had not undergone any change. Whether this deepening arose from the projection of the piles alone is doubtful, as the sand appeared to have decreased at the margin uniformly to the east and west. Still the obstruction of these piles to the current of the stream, though small, appeared to have had some influence; a slight hollow was worn around each pile, similar to what takes place on the sea-shore, around stones lying on the sand.

Early in January, 1839, the sand was found to be 4 inches lower, on an average, than in September of the previous year, being curtailed to the east of the piles, and extended to the west. In April it was, on an average, 7 feet 5 inches below the tops of the piles; being a total decrease of 3 feet in height, from the time of their being screwed down.

As the sand shifted so much, it was thought advisable to adopt some precautionary measures, to secure a foundation for the building. A raft, or grating, of timber was accordingly formed, (Fig. 2, Plate 6,) and early in June it was towed down and moored off the sand. The levels of the sand had been observed early in the month, and were found about the same as in the previous April, and they were again tried on the 24th June, before sinking the raft, when the sand was found more level and at about the same height as when the last observation was made. The timbers of the raft were so disposed as to admit the piles freely, and a curb extended all round, for retaining the stones intended to be placed upon it; the surface was covered with bavens, or faggots of small wood, filling the spaces level with the tops of the upper half timbers, and were fixed by means of ropes, interlaced with them and nailed to the timbers. The raft, in this state, was towed over the piles, from the tops of which leading ropes had previously been brought through the corresponding openings between the timbers: this precaution was necessary from the inequality of the sides of the octagon. One hundred and twenty tons of rough Kentish stone, were then thrown upon the raft, covering it to an average depth of 15 inches, causing it to sink with about two-thirds of this weight, and to ground just before low water.

From the sand having decreased so much previously, particular care was taken to obtain the levels of the raft so as to ascertain in future the amount of settlement, and on the 1st July following, it was found to have settled on an average about 8 inches: it had gone down to the N.E. about 20 inches, and at the S.W. it had risen 4 inches. As it had settled so very unequally, it was determined to endeavour to counteract this, by placing some additional stone on the highest part; sixty tons were accordingly added on the 30th July, the greater portion being placed to the W. and S.W. In the course of the next day there was a fresh gale from W.S.W. and the raft, from the additional weight, sunk 1 foot 7 inches, and became more level; in August following it was again tried, and found to be in about the same condition.

In November, from the gales that prevailed, the raft was found to be 14 inches lower and more out of level, being 2 feet lower on the north than on the south side. In April, 1840, it had again settled 15 inches; but was more horizontal, being but 10 inches out of level, and the curb to the northward was covered with sand; early in July it was found to remain the same as to level, and the sand had accumulated more around it.

Early in the summer of 1840, orders were given to proceed with the work for the superstructure, and the tenders of Messrs. Gordon and Co., of Deptford, for the iron work, and of Messrs. Gates and Horne, of Poplar, for the carpenter's and joiner's work, of the proposed construction, having been accepted, both portions of the work were properly fitted and erected at the establishments of the Contractors, before they were sent down to the sand.

The iron work was taken down to the sand on the 19th August; the cast-iron bases were first shipped over the pile heads, and dropped upon the stonework of the raft, and solidly bedded: on the tops of these bases were placed concentric rings, forming washers, fitting loosely over the piles, and of various thicknesses, so as to render the bases of one uniform level at the top.

The columns were all put up, and the wrought-iron work was fitted early in September; a stage was then erected on the upper horizontal braces, to facilitate the erection of the timber framing, which was so far advanced by the middle of October, that the lantern was sent down, and the whole was completed early in the year 1841.

The lighting apparatus and lantern were manufactured by Messrs. Wilkins and Son, of Long Acre: and the light was first exhibited on the night of the 10th February, 1841. It is a French dioptric light of the second order; its centre is 45 feet above the mean

level of the sea, and at this elevation it may be seen from the deck of a ship for a distance of nearly ten miles. (Fig. 3, Plate 6.)

A bell is fitted on the gallery, to be sounded at regular intervals in dark and foggy nights, by means of clock-work within the lantern base.

A space of 2 inches was left between the tops of the bases and the lower ends of the columns; so that, in the event of the piles sinking with the weight of the building, after settling 2 inches, the structure would rest upon the bases, and through them on the large bearing surface of the raft, amounting to about 1700 square feet, being fifteen times the area of the nine screws, the bearing of which is 113 superficial feet, being 12·56 feet to each pile.

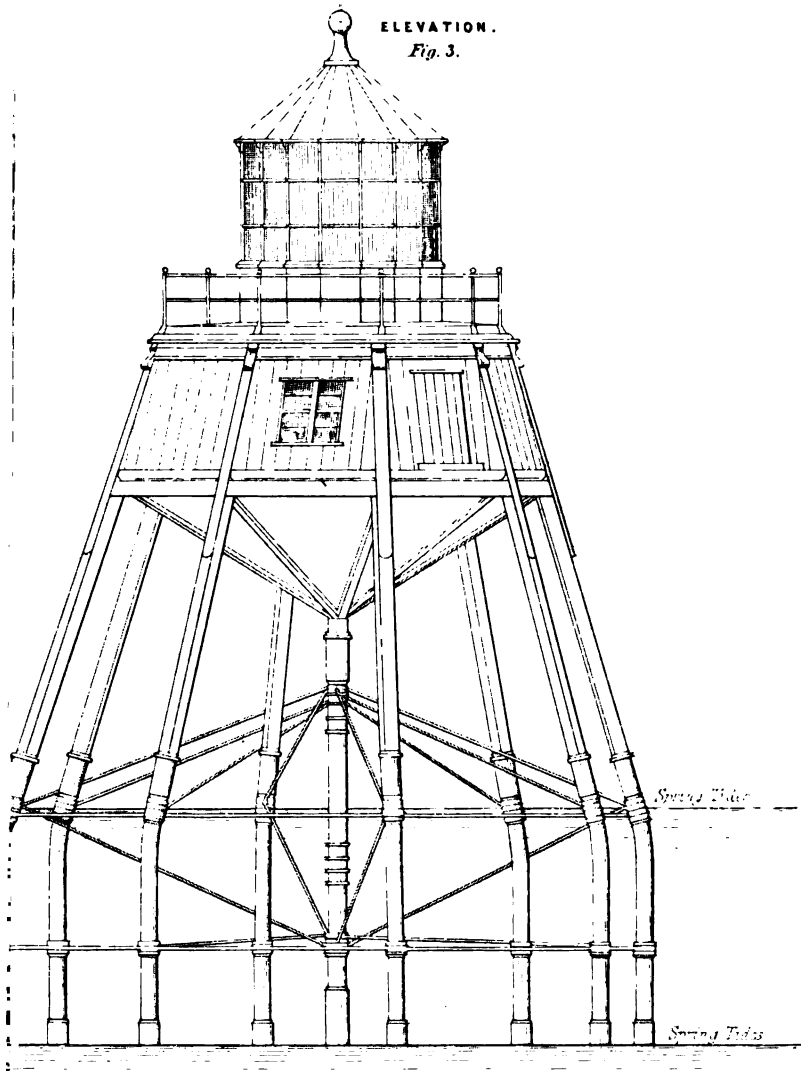
As the water ebbs at times below the tops of the bases, the piles were exposed for a length of 2 inches, giving the bases a somewhat weak and unsightly appearance. To obviate this, nine covering irons were cast, the exterior ones being 2 feet in length, and the centre one 3 feet; they were each formed of two semicircular pieces, fitting together with lapped joints, and screwed with countersunk screws, having each a projecting flanch inside to support them on the bases. The upper part of the bases and the lower ends of the columns, were thus enclosed, and at low water these covering irons had the appearance of bases to the columns, and they fitted loosely, so that, in the event of any settlement, they would offer no obstruction to the columns. A mark was made on the outside of each column, 12 inches above these bases, to ascertain if any subsidence did occur. This, of course, could only be observed to the extent of 2 inches, when, as before described, the structure would bear upon the raft. If, however, any further subsidence should take place, it can be ascertained by means of other marks that have been made for that purpose; but up to the present time not the slightest settlement of the building has taken place.*

The total weight of the structure is about 72 tons, being a weight of 8 tons per pile, or 12¾ cwt. per superficial foot of bearing surface of the screws, at the ends of the piles.

The paper is illustrated by three drawings, Nos. 3375 to 3377, from which Plate 6 is compiled.

* No subsidence of the building has been observed up to the middle of the year 1848.

ELEVATION.
Fig. 3.



Published by the Society.

APPENDIX.

Description of the Construction.

The iron work supporting the superstructure, and placed immediately upon the screw piles, consists of nine hollow cast iron columns, or pipes, the exterior ones curved at the top to a radius of 21 feet towards the centre, with projections to support the wrought-iron collars to which the ties are bolted. The columns, at 4 feet from the bottom, have a stop cast in them to rest upon the piles, and are finished at the top with a socket to receive the timber columns of the superstructure; the centre column is shipped 2 feet over the centre pile; the columns at each end are strengthened by wrought-iron hoops, put on hot, and suddenly cooled. The ties are of wrought-iron, connected to the outer columns by collars with arms, embracing the ends of the ties which are flattened out; the ties at the centre of the building are finished with projections, forming part of a circular collar, which encloses the centre column; the projecting flanges are bolted together; the braces are arranged so that there should be a tier of horizontal ties between the outer columns, about 10 inches above the pile heads, and similar ones radiating from the centre column to the north, south, east, and west columns. Four sloping diagonal ties connect the centre column to the N.E., N.W., S.E., and S.W. columns, near the level of the upper horizontal ties, and are fixed in the same way as the lower ones. These horizontal ties are attached immediately below the sockets in which the timbers rest, at which level, sloping ties connect each of the exterior columns to the upper part of the centre one, which stands 7 feet above the rest.

The columns of the timber superstructure are stepped into the iron columns, and are well braced together; the tiers of horizontal bracing form the supports for the floors and gallery. The braces are partly supported by oak cleats, screwed to the uprights, to which the half timbers are bolted, and the whole timbers abut against them, being partly let in and secured by wrought-iron gibs, and keys, and cleats, and attached at the centre by wrought-iron knees and bolts.

The superstructure is further strengthened by a raking brace being placed at every external column, at the level of the lower floor, and abutting against the centre column, into which four of them are tenoned, and are secured by wrought-iron knees and bolts, the upper ends being bolted to the half timber braces of the lower floor; the lower ends of the remaining raking braces are stepped upon the others, and at the outer ends are fastened to them in a similar manner. Between each of these braces quarters are fixed, and the whole is boarded inside and out, forming the store for coals, water, &c. Both the tiers of horizontal bracing are bounded by curbs, which fit in between the main pillars, and are fastened by wrought-iron knees, and through bolts; the upper curb is level with the tops of the pillars. The joists of both floors are caulked on to the horizontal bracing, those of the lower floor being tenoned into the curb.

The lantern base is supported upon a curb, in pieces 8 feet long, the ends of which are half-lapped, bedded on, and bolted to the upper horizontal braces. The basement, or plinth, consists of sixteen sides, the angles being formed by two

quarters, tenoned below into the curb, and at the top into the cill of the lantern, which is of oak, weathered and throated, and the joints dove-tailed and half-lapped: the quarters are well braced, and the wrought-iron through bolts, which hold down the lantern, pass between the quarters at each angle, and are screwed up underneath the lower curb of the basement. The plinth, or basement, is covered with two casings of boarding, an inch thick, the inner casing being placed horizontally, and the outer vertically. The joists of the lantern floor are laid, like those of the lower floor, upon the horisontal bracing and the lower curb of the lantern base; the joists of the lantern gallery rest upon the curb of the lantern plinth and upon the upper outer curb, radiating nearly from the centre, there being one at each angle, and the whole is covered with boarding, which receives the lead flat.

The sides of the dwelling are covered both on the outside and the inside with boarding; the joints are ploughed and tongued, and each board is strongly nailed to the three tiers of quarters; the outside boarding at the bottom, is rebated into an external moulded curb, which is fixed to the outside of the principal curb, and the principal posts, or columns, are rebated, for a width of 2 inches at the angles, to receive the boarding; and the faces of the columns are covered with pilasters, or covering boards, rounded on the edges, and reaching about 3 feet 6 inches below the lower curb, being terminated at the top by brackets, against which the cornice abuts. The gallery and cover boards of the cornice are covered with lead.

The window-frames are supported in a frame-work, the posts of which receive the quarters of the sides; the window cills are of oak, weathered, and throated in front; the sashes are single, and, like the shutters, slide up and down inside the outer boarding.

The door is on the N.W. side, and the quarters of the side are tenoned into the posts, the jamb linings being nailed to these posts; the cill is of oak, throated and weathered, and the head is finished like the jambs. The two leaves of the folding-doors are framed and battened with deal 2 inches thick, and when shut they are flush and fair with the outside of the dwelling.

The interior of the dwelling is arranged and partitioned off, so that the sleeping berths are kept distinct from the living room, by having small state rooms and doors in front. The store has bins for tow, provisions, &c.; in it are kept the oil cisterns, and the stairs up to the lantern are enclosed by partitions. The communication with the lower store, in which coals are kept, is by a trap close to the entrance doorway; the water-closet and water-tanks are likewise placed in this lower store.

Outside of the entrance-door is a landing, or platform, from which the ladder descends to the level of the top of the N.W. iron column, where it is supported by a cast-iron bracket; on the surface of this ladder, the second length slides upon rollers travelling on wrought-iron plates. This portion of the ladder reaches to near low water, and is raised by means of a rope and barrel, worked by a ratchet-wheel and lever, the rope having balance weights at the other end, which slide up and down against the face of the pillar. There is likewise a break for lowering it: by this contrivance the building can be reached at any time of the tide, as the lower end of the ladder, when let down, reaches sufficiently near to the surface of the water at low tide to enable persons to land on it.

PRINCIPAL DIMENSIONS, SCANTLINGS, &c.

Iron Work.

Screws	4 feet diameter
Piles	26 feet long, 5 in. „
Cast-iron columns (external) and 1½ inch thick.	18 „ 11 in. „
Lower wrought-iron ties	2½ in. „
Upper ditto	2 in. „
Wrought-iron screw-bolts to couplings of ties	⅞ in. „

Timber Work.

External columns, 30 feet long, 12 inches square at the bottom and 10½ inches at top.

	Inches.	Inches.
Half timber horizontal braces	12 ×	4½
Upper whole ditto	10 ×	10
Lower ditto	11 ×	10
Raking braces	10 ×	10

Joiners' Work.

Lantern curb	12 × 9
Oak cill to ditto	12 × 6
Oak window cills	12 × 9
Oak door cill	12 × 9
Door posts	6 × 5
Jamb linings to door	2½ thick.
Outside boarding to sides of dwelling	2 „
Inside ditto	1½ „
Pilaster boards	2 „
Boarding to lower store	2 „
Ditto to lead flat	2 „

Mr. WILKINS stated, in answer to questions from the President, that he had seen the Edystone and the Maplin Sand Lighthouses during severe gales of wind; that, as might be conceived from the nature of the construction, the latter building was more affected than the former by the striking of heavy seas: the motion appeared to be more like torsion than simple vibration, which he attributed to the waves striking the ladder and its projecting stage, and thus tending to twist the upper part. Still the motion was not such as would cause injury to the building.

Mr. WALKER, President, pointed out two diagonal braces, extending downward from the end of the ladder stage to the piles on either side; these had been introduced in order to counteract the twisting described by Mr. Wilkins. In constructions of this nature, it was of importance to oppose as little resistance as possible to the waves, especially in the upper part of the building; a system of

bracing had therefore been adopted, which consisted principally of two series of continuous circular horizontal ties between the piles, at the several heights of 6 feet and 15 feet above low-water mark of spring tides. From the external ring of piles, two sets of diagonal stays extended to the centre pillar, forming strong triangular trusses, in the direction of each pile, and two sets of horizontal stays stretched between the piles and the centre pillar, at the levels of the circular bands. The amount of direct vibration was very small, and he did not conceive that the twisting motion which had been described, was sufficient to warrant the introduction of diagonal braces between the main piles, which would materially augment the surface upon which the waves would act.

Mr. VIGNOLES directed the attention of the meeting to the system of diagonal bracing between the piles, which had been adopted at the Fleetwood on Wyre Lighthouse. He apprehended, that as the principal force of the waves would be exerted against that part of the structure which was above the level of high water, the diagonal braces extending between the upper part of the piles and the level of low water, were preferable to the horizontal continuous bands of the Maplin Sand Lighthouse, although they were aided by the system of radiating central truss braces which it possessed; he conceived that both buildings were strong enough for the purpose for which they were constructed; but he preferred the mode of bracing adopted in the Port Fleetwood house, the vibration of which he knew to be very small, although it was situated in an exposed position, where the rise of tide was 30 feet.

Mr. DONKIN observed, that there could not exist a doubt of the introduction of diagonal braces rendering the building stronger; how far they were necessary, or might be prejudicial, in offering additional resistance to the passage of the waves, should be well examined, before adopting them. He considered the position of the suspended ladder decidedly objectionable, as any torsion, caused by the waves striking it, must tend to dislocate the fibre of the material of the piles, and to fracture them.

Mr. FAREY believed the construction of the Maplin Sand Lighthouse to be better adapted than that of the Fleetwood Lighthouse, for resisting the direct action of waves; but the diagonal bracing of the latter enabled it to withstand torsion better than the hoop bracing of the former. He inquired, why the lower part of the light-keeper's house was made conical? He apprehended that it would receive a heavier blow from a wave than if it had been flat.

Mr. WALKER, President, replied, that the main body of the waves seldom, or never, rose so high as the bottom of the house,

and that the conical form allowed the air and spray to rise up and be guided off, without affecting the building, as it would have done, if the bottom had been flat.

With regard to the torsion, that had only been felt at first, when the ladder extended too low down, and received a constant succession of blows from every wave, which naturally communicated a vibration to the whole structure: the ladder was now shortened, and nothing of the kind was felt, indeed the waves scarcely, even in the roughest weather, struck the suspension stage, or the boat. He preferred the continuous horizontal bracing, which bound all the piles firmly together like the staves of a barrel, and from observations he had made, he believed the amount of vibration to be greater in the Port Fleetwood Lighthouse, than in that at the Maplin Sand.

In answer to a question from Mr. G. H. Palmer, the President said, that at present (four years after the construction of the building) there was not the slightest indication of change in the condition of the cast-iron from its contact with the salt water.*

Professor BRANDE was unable to adduce any additional evidence on the observed facts connected with the change suffered by cast-iron, when exposed to the action of salt water, or in mines and in various other positions. From experiments which he had made, he was led to believe, that many of the appearances observed in the changes of cast-iron, arose rather from a peculiar mechanical combination of the molecules, than from a difference in the chemical constitution of the metal; no difference could be detected by analysis in the metal which had undergone change and that which had not.

It should be remarked, that the contact of two metals was not essential to cause galvanic action; a film of oxide upon the surface of the body of metal formed a very active galvanic pile: hence arose the necessity of preventing oxidation, by proper paint, or varnish, before using cast-iron in exposed situations.

Mr. FAREY observed, that in the early engines constructed by Woolf, in Cornwall, in which the packing segments were of gun-metal, and the body of the piston was of cast-iron, wherever the two metals were in contact, the iron was turned to plumbago; this had been particularly observed where high-pressure steam was used. It might be a question whether the temperature of the steam, and the quantity of mineral water carried over with it, by the large amount of priming of the engines in that day, had not materially contributed to produce the effect.

* In 1848, after ten years' immersion, neither the cast nor the wrought-iron appear to be at all affected by exposure, or by the action of the salt water.

Mr. P. TAYLOR believed, that the temperature of the steam had not any connexion with the subject. In the metallic packing of steam pistons of low-pressure marine engines, which he had constantly under repair at Marseilles, he found, that wherever the wedge pieces were of gun-metal, the backs of the cast-iron segments were converted into plumbago, while those surfaces of cast-iron which were ground together and worked against each other, remained unchanged; the same might be said of the rubbing surfaces of cast-iron against gun-metal; it appeared, therefore, that the formation of an oxide was necessary to commence the change. He repudiated the use of cast-iron in situations where these changes were to be apprehended; he would employ wrought-iron, as although that did become oxidized, it retained its relative strength to the last, whereas cast-iron, when changed into plumbago, retained its bulk, but lost nearly all power of cohesion.

Mr. J. TAYLOR said, that in Cornwall, the cast-iron pump-trees exposed to the action of mine water, were very speedily destroyed; and even although they were 1½ inch thick, they could be cut to pieces with a knife, when first taken out of the pit. The air-pump buckets of steam-engines, in which the body was of cast-iron and the valves of gun-metal, formed the most perfect kind of galvanic apparatus; they should be made entirely of gun-metal.

In manufactories of vinegar and pyroligneous acid the decay of cast-iron was very rapid.

Mr. GLYNN attributed, in a great degree, the rapid decay of cast-iron in coal mines, to the presence of sulphuric acid evolved from the pyrites.

Mr. P. TAYLOR agreed with Mr. Glynn; even copper pipes were rapidly destroyed in the bilge water of vessels, which always contained much sulphuretted hydrogen. He recommended the use of stout lead pipes in such situations, as they would be found much more durable.

Mr. DAVISON had found it necessary to substitute gun-metal gratings for the cast-iron ones, at Messrs. Hanbury's Brewery, as although they were ¾ inch thick, they had been entirely destroyed in four years.

Mr. WALKER, President, mentioned incidentally a lighthouse constructing by Messrs. Gordon and Co., at Deptford, under his directions, for the Point of Ayr. The lantern for it would be cast from a gun which had been raised from the wreck of the Royal George.

February 29, 1848.

JOSHUA FIELD, President, in the Chair.

No. 777.—"Remarks on the Formation of Entrances to Wet and Dry Docks, situated upon a Tideway; illustrated by the principal examples in the Port of London." * By John Baldry Redman, M. Inst. C. E.

THE importance of this subject is so great, that lengthened prefatory remarks would be superfluous; the instances which may be observed on the Thames, show that there has been considerable variation in the opinions and practice of engineers, or that the subject has not been considered important, though, at the same time some allowance must be made for the peculiar circumstances of the Port of London, and the value of ground upon its banks; the question therefore is, what should be the proper direction and shape of a dock entrance in reference to the run of tide.

The practice in the Port of London is to dock a ship upon the flood, just before high water, and to undock her at about the same period of tide; high water is also selected, for obvious reasons, as the time for launching new vessels from the building slips. The angle these docks and entrances make with the line, or direction of the run of tide, is a very important element for consideration, much greater working facilities being afforded at some than at others, where, from their particular direction, expensive additional timber outworks have been rendered necessary, to afford those facilities which the entrances, when finished, did not afford.

It is only necessary to refer to the particular position of some of the principal entrances, to exemplify this.

Plate 7, Fig. 1.—The entrance at Blackwall of the East India Docks is considered by shipwrights and pilots of the port to be well situated; it points upwards, at an acute angle with the line of flood, and is at the same time covered, to some extent, by a projecting pier on the lower side; the effect is, that on a vessel entering, her stern being driven upwards by the action of the tide upon her starboard quarter, she is drawn by warps without much difficulty into the lock; this, however, is to an extent only, as, with the wind on shore, a vessel is sometimes driven athwart the entrance, and nipped between the

* The discussion on this Paper extended over portions of three evenings; but an abstract of the whole is given consecutively.

lower pier and the projection of the Brunswick Wharf, against which her larboard quarter is driven by the flood and wind. This position is shown by the form of a vessel within the entrance. In this state of affairs it becomes necessary to wait for slack tide at high water, which sometimes, with a large and heavily laden ship, is a dangerous experiment; or else, to heave her stern down against the tide from the starboard quarter. This operation, with an entrance so placed, is by no means so laborious as if it had been placed at right angles to the stream. To the natural position of this entrance, however, much of its superiority is attributed, there being plenty of room in the river in front of it, nor does the tide set strongly across it; but with easterly gales, large ships would formerly hang until the slack of tide, whereas now, with the assistance of steam-tugs, vessels may be docked as soon as there is sufficient depth of water.

This entrance was formed for the purpose of docking a limited number of large vessels on any one tide. It has been stated, that it was with this view that the outer lock gate was projected so far outwards, towards the river; the circumstances and conditions of the lock are consequently similar to those of a graving dock, and it is supposed that it was so formed with the view of waiting for the slack of tide, this would preclude docking more than one, or two vessels upon the tide, which, however, would have sufficed for the original requirements of the India trade.

The majority of the docks and slips at the respective establishments of the Messrs. Wigrams and Messrs. Greens, at Blackwall, point more acutely to the flood tide. These docks are considered by ship-builders to be well placed; they are, however, much exposed, as the flood tide sets right into them; this, however, is not of such importance as for the entrance of a wet dock, because a shipbuilder, having only one, or at most two vessels to take into one dock, can afford to wait for the slack tide.

Plate 7, Fig. 2, shows the entrance at the Blackwall end of the West India Docks and of the City Canal, now the West India South Dock. This was influenced no doubt by the position, and the object of the latter, which was to effect a through communication for the navigation, and to cut off the reaches round the Isle of Dogs; but which failing as a canal, has long been used as a lie-by for ships and timber. The entrance is nearly in an opposite direction to that of the example first quoted, and forms rather an obtuse angle, or at least a right angle with the flood.

It is stated by gentlemen who have been many years connected with the port, that when the West India Docks were first completed,

the danger to loaded ships was so great, that it became necessary to lengthen the upper pier, by additional timber external works. The entrance, in its present state, bears a very good character.

This entrance was formed with a view to docking the largest possible number of vessels upon one tide (having reference to the arrival at that period of the West India ships in fleets). The basin was formed as a tide receptacle for these vessels as they came up the river, the water being drawn down to about half tide level in the basin, for that purpose; the great width of entrance was no doubt allowed for vessels to sheer in as they came up; this, however, was not found practicable, it being necessary (as is now done), to bring the vessels up with head to tide, and allow them to drop up from the buoys off the entrance, across which the flood tide runs up with strength; it was also found necessary to carry out a timber jetty to low-water mark, off the South, or Upper Pier, to prevent vessels from tailing round with the flood on to the shore. The great width thus eventually obtained between the wings is advantageous, as it allows a vessel to kant across, and to enter without the assistance of a quarter-rope, or a steam-boat; another advantage is, that in undocking, sufficient space is allowed for the outward-bound vessel to pass out, the inward-bound vessel being at the same time within the entrance.

Mr. Pitcher's graving docks, to the westward of the canal entrance, are in nearly the same direction.

Plate 7, Fig. 3.—The Blackwall entrance of the South Dock answers well as regards direction, although, like the last, it is nearly at right angles to the stream, as, from its being more in a bight, there is a slack of tide across it; it, however, requires a dolphin upon the upper side at low water, to counteract the tendency which vessels have, when docked upon the flood, to tail upon Mr. Pitcher's ways.

Plate 7, Figs. 4 and 5.—The Western, or Upper entrances of the West India Docks and City Canal, or South Dock, at Limehouse, are favourably situated, as they point acutely up the stream, and considerable facilities are afforded to vessels entering, by the West India Dock entrance, on account of its direction; the admission and the exit of light vessels can thus be well and expeditiously conducted.

The West India Dock entrance is considered well adapted to the purposes of trade, as there is deep water on the north side, and there is an easy run of tide across it towards high water.

At Woolwich Dockyard there is great variety in the direction of the building slips and of the graving docks, some are nearly square to the stream, in other instances they point slightly up, and in

others downwards, forming an acute angle with the line of flood in some instances, and an obtuse angle in others.

At Deptford Dockyard there is equal variety; at the lower part of the yard they are nearly at right angles to the stream; the entrance to the lower basin points slightly up the stream; that to the Transport Dock is nearly square; a dock above it is in the same direction; but the dock above, in what is called "Dudman's Dockyard," points up acutely to the flood; a building slip above this is in the same direction, and a dock entrance still higher up, points upwards at a less acute angle. The conditions of the several properties appear to have had as much influence upon the direction of these slips and docks as any other considerations.

Plate 7, Figs. 6 and 7.—The entrance lock to the East Country Dock points slightly upwards, as also that to the Commercial Docks; both are considered good working entrances; the Graving Docks on either side of the Commercial Docks entrance point in a similar manner, showing that the disposition of one property has influenced the other, as regards direction.

From the particular local set of tide, the angle of direction upwards is very much reduced.

At each of these two entrance locks, two dolphins are placed in a line with their upper sides; they are *pro tanto* elongations of the upper wings.

On the opposite side of the river at Mill Wall, Blackett's Graving Dock is nearly square with the stream, pointing slightly downwards.

The Graving Dock above this (Mitchell's), below Messrs. Seaward's Factory, points up very acutely with the line of flood.

The docks of Messrs. Fletcher, situate between the Limehouse entrances of the West India Docks, are nearly at right angles with the river in their immediate neighbourhood; but as regards the general contour of the reach, point slightly up the stream. Very nearly the same remark will apply to the docks of Messrs. Young at Limehouse; the character these docks bear on the river is very similar, except that as Fletcher's Docks lie in a bight, they are less exposed.

Limekiln, or Limehouse Dock points up the stream; the small dock at Duke Shore belonging to Messrs. Young, though standing relatively very similar in position to their other docks, is stated by them to be perhaps the most awkward dock in the river, owing to the flood tide from Limehouse reach setting right into it, and they consider that had its entrance been much wider, or its direction much more acute with the line of flood, much of this inconvenience would have been avoided.

Plate 7, Fig. 8.—Messrs. Dowson's Graving Dock at Limehouse is nearly square to the stream; but from the particular set of tide in this portion of the reach, the flood making over from Cuckold's Point, this dock points at a very obtuse angle towards the flood, as shown upon the diagram; great difficulty is consequently experienced in docking a heavy ship, a considerable purchase being necessary to keep her in position until near high water, by heaving down her stern against the tide; the evil at this dock, and the one at Duke Shore, is increased by the strength with which the flood tide sets directly into them.

There is a considerable length of outer tidal basin, or entrance to this dock, between the gates and the river; but as the quays, or wing walls which form the sides are parallel to one another, and in a line with the sides of the dock, it is obvious, that no advantage is gained, in reference to the particular direction which a vessel assumes whilst entering. This length of entrance appears likewise to have been principally induced from the particular local position of the dock, a public street crossing it, and the site of the swing bridge consequently determining the commencement of the dock; this latter remark likewise applies to the next example, which is shown in the same illustration, being close adjoining, and nearly parallel, to Messrs. Dowson's Dock, but pointing slightly down the stream, and consequently forming a more obtuse angle with the flood than even the last example, and is therefore, as regards direction, even more awkwardly situated; but the widening out of the wing walls, forming the entrance, slightly increases the facilities for vessels, both departing and entering, but the tonnage of such vessels is inconsiderable.

Plate 7, Fig. 9.—The Regent's Canal entrance lock, which leads into a large basin, or wet dock, admitting vessels of considerable burthen, principally colliers and coasters, is nearly square to the stream; but from the tide setting across, upon the flood, from the opposite side, induced by the local formation of the river, though not in so great a degree as in the last examples, this entrance forms in the line of its direction an obtuse angle with the set of the flood. It has a very bad character, on account of its direction and the small distance between the wings at the entrance, which had no room for expansion, from the gates being, as in graving docks, close to the river bank. The difficulty of docking a ship upon the flood, must have been very great before the addition of the timber-works, which, in effect, remove the entrance gates further from the run of tide, creating slack water in front of them, and, by giving a greater width between the jaws of the entrance, allow somewhat for the

necessary obliquity in entering, and afford more space for a vessel's bow to be turned down whilst departing.

Plate 7, Fig. 10.—Lavender Graving Dock, Rotherhithe, bears an excellent character for its convenience for docking; it is nearly at right angles, pointing slightly up the stream. But its character, as must be evident from former examples, is not dependent upon its direction, as from the particular set of tide away from it, in consequence of the tide setting from the point below on the same side to the opposite shore, it is left in an eddy, and consequently in slack water. It becomes for these reasons nearly similar in its conditions to a dry dock from a harbour, wet dock, or other still water; it therefore cannot be taken as an example in point, except so far as showing that there are particular localities and bights upon a tidal river, where the direction of the entrance becomes of less importance. Even there, however, from the gates being placed so near to the river, the platform is carried beyond the wharf-line, and the necessity for the extension of piers to form a chamber has been involved. The object in this case, and with ship-builders generally, has been, no doubt, in placing their gates so close to the river, to get as great a depth of water as possible with the least amount of excavation, to shorten the dock as much as possible, with reference to the expense of construction and the cost of land. In many situations on the Thames the existence of a road, or street parallel to and not far distant from the stream, has been the cause of an encroachment upon the river.

Plate 7, Fig 11.—The Shadwell entrance of the London Docks points so much down the river, as to form a very obtuse angle with the stream. The inconveniences that would otherwise result to vessels entering are, from various causes, obviated at this entrance, which, in fact, bears a very good character. One of these causes is, that the set of the flood tide is across the river, towards the opposite shore from the bight below the entrance, which is left in comparatively slack water, and is thus more at right angles with the flood on account of this particular set. The great width between the wings and the additional timber external works also afford great facilities, both when docking and undocking vessels. In this latter case the capabilities arise, like those at the Blackwall entrances of the West India Docks, from the judicious construction of the external works, which, however, have in both instances been, to a great extent, of subsequent formation, to obviate evils attendant upon the original form. It will at once be seen, by referring to the plan of this entrance as it now exists, that the conveniences for docking must have been much less, before the external works were

added. The timber pier added to the western, or upper wing and the dolphin, form, with the northern portion of the wing wall, a line of direction pointing up the stream, which is the desirable direction for docking a ship upon the flood as she swings round, her larboard quarter coming in contact with the dolphin, and her starboard bow with the timber pier; she is thus prevented from tailing upon the shore on the upper side, as she would otherwise have done without these external works. The timber pier and dolphin on the lower side, perform the same office towards a vessel leaving the dock just after high water, or being docked, when there is no run of tide, and the south-west wind blowing her on to the shore below the entrance.

Much of the external wing wall on the lower, or eastern side, might have been dispensed with, had the direction of this entrance been more at right angles to the stream; it is, however, to be observed, that this direction would not have suited so well as the one adopted in the general plan of the docks. This entrance possesses an advantage pointed out in the instance of the Blackwall West India Dock entrance, from the great width, allowing two vessels to pass.

Mr. Henry R. Palmer, the Engineer employed to construct this entrance, published in 1828, a paper entitled "Report on the Proposed Eastern Entrance to the London Docks."*

In that paper Mr. Palmer says:—

"The taking of a ship into a harbour is required to be performed by the persons on board, and therefore the line of direction of the entrance is made as simple as her security from the wind and its consequences upon the water will allow. If the same force can with safety be employed to conduct a vessel to still water, which has taken her to the mouth of it, the entrance will be performed with most ease.

"On the sea coast, the wind, and its consequences upon the water, constitute the principal forces to be contended with; the current of the water being comparatively of little, or no value. On a river, the current of the water becomes an essential force, and that in proportion as the width of the river is diminished.

"It is obvious, that in both cases, it is preferable to make these forces subservient to our purpose, when it is practicable, and in the formation of an entrance to a harbour, or a dock, its position, direc-

* The Author had not the advantage of an inspection of this document, until after the compilation of his own remarks, as he had been unable to obtain a copy until after the discussion had commenced, when one was lent to him by a former Assistant of Mr. Palmer's.

tion, and form, should be such as to expose a vessel to as little action as possible, not available to this object.

"The communication between a river and a wet dock, being through the medium of a lock, whose limits but little exceed the dimensions of the ship that passes through, it is important that the water about the entrance to that lock should be, if possible, quiescent. If it have a running, or turbulent motion, considerable labour is indispensably necessary to conduct a vessel within its narrow channel with safety; we therefore find, that many of the public docks are provided with an external area, or basin, which is in fact a harbour, whose entrance is sufficiently wide to admit vessels during most weathers, while at the same time it has the effect of producing still water where that is required."

The adoption of this principle upon the Mersey and upon the Humber, on account of the heavy sea, is referred to; also the entrance to the Hull Docks, from the river Hull being formed in a recess or fore-bay.

The entrance to the Bristol Docks is referred to by Mr. Palmer, as a precedent for the case then under his consideration, where the entrance locks point down the stream and form an obtuse angle with the line of flood, and where, as Mr. Palmer says:—

"Vessels go up with the flood tide only, and sail most generally at once into the entrance. When the wind is high and corresponds with the tide, a rope is sent on shore opposite the entrance, and being connected with the stern, the ship is easily presented to the lock, and is conducted into still water without risk."

It may be observed, that the extreme narrowness of the Avon necessarily induced such an arrangement.

The particular position of the entrances to the Runcorn Docks is next reviewed; those through the locks, Mr. Palmer describes as "parallel with the current," in reference to which he subsequently says:—

"Inasmuch as the vessels are not required to deviate from the direction of the current (*i. e.* to lie across it), not only is their introduction not made difficult by the motion of the water, but actually accomplished by it without risk."

Of the docks in the port of London, Mr. Palmer says:—

"When we contemplate the immensity of the traffic on the Thames, and the extent of accommodation afforded to the shipping, as compared with other ports, it is surprising that the entrances to the numerous docks should be less convenient than those on rivers, whose navigation is more difficult. The entrances are all narrower,

so that when the head of a ship arrives within its confined space, the stern is opposed to the action of the current."

Mr. Palmer then describes the entrances to the principal public docks, and the labour entailed at the graving docks on account of their position; in reference to this he says:—

"Now as the force of the water upon the ship is the same between the same parallels, the strength required to resist it will be the same, whether the head points up or down the stream. But, it is argued, that if the entrance coincide with the direction of the stream (*i. e.* points down), the vessel may be forced against one of the side walls; and if no exertion be made to prevent such an effect, it undoubtedly would sometimes occur. But the vessel must be controlled by ropes at the stern, connected with a mooring, with less force in this position, than when laid across the stream, and proportionally so in all the intermediate angles.

"Now if the entrance point up the stream, the vessel must be allowed to pass first above the entrance, and then be drawn towards it with a force greater than that required to resist her motion, as in the former case, because the motion of the stream is added to that of the vessel. Although the difference in the quantities of force and labour may not be great, the direction of the entrance, if narrow, should be guided by localities, such as the position in the river, the position of moorings, &c."

After stating that the above reasoning applied to narrow entrances, with the gates close to the river, inapplicable for the London Docks, and referring to the want of width at most of the entrances, and the too close proximity of their gates to the stream, Mr. Palmer describes his plan for the Shadwell entrance, in accordance with the principles above laid down, and which was subsequently carried out under that Engineer.

That entrance, however, by additional outworks, resolves itself into a very different form.

Plate 7, Fig. 12.—The entrance to the Grand Surrey Docks and Canal, Rotherhithe, points slightly down the stream; but from the local set of the tide from the opposite shore, its line of direction forms a very obtuse angle with the set of the flood. The effect produced by this is evinced in an external timber jetty and dolphin, off the upper side, by which a vessel is brought up upon the flood, in the right position in a line with the entrance, which is obviously insufficient as to width and length, when the set of the tide is considered, without these external works. The direction of this entrance has probably been influenced by local circumstances connected with neighbouring properties.

Plate 7, Fig. 13.—The Wapping, or central entrance of the London Docks is situated at right angles to the stream. Its direction in such a position must no doubt have been influenced by local circumstances. Its direction for the two purposes of docking and undocking is tolerably eligible; but there is a deficiency of length towards the river, and splaying out of the wing walls; dolphins have consequently been rendered necessary, but they are placed at such a distance out as to act similarly to the moorings at other entrances. There is a local eddy of the tide off this entrance, which makes its direction of less consequence. It is principally used for small vessels and barges.

The upper entrance of the London Docks, called the Hermitage entrance, is nearly square to the stream, or inclining slightly downwards. This entrance is not used; the principal trade is thus carried on at the lower eastern entrance at Shadwell, where large sums of money have been expended in the repairs and improvement of the immediate outlet or entrance.

St. Saviour's Dock entrance, on the opposite side of the river, points very much down the stream; but it is supposed by persons connected with the port, that its original formation was out of some natural inlet in the shore, outside the marsh wall, and, being only a tide dock, the direction of the entrance was not considered so much an object, as in the neighbouring works. It would, however, be supposed, that the direction of the entrance to such a dock was a consideration of importance; but a comparison of this example with that of Limekiln Dock on the opposite side, and which has before been quoted as pointing acutely up the stream, shows how various have been the modes of treating these tidal constructions.

Plate 7, Fig. 14.—The St. Katherine's Dock entrance points slightly down the stream. There is at that spot a great depth of water, and ships are frequently docked after the tide has fallen, according to the judgment of the dock-master, whether it can be done safely. Under these circumstances the direction up, or down, is not of the same importance as in other examples. But an evil is entailed at these docks, by the small amount of width between the wing walls at the entrance; the particular locality must, however, have necessarily involved this, and the wings were probably projected and splayed out as much as the nature of the site would allow. The object here also was to dock ships quickly, and also upon a falling tide. For this the lock has three pairs of gates, the outer pair being placed as close to the river as possible. The fact of a public street here running parallel to the river, and the entailment

of a swing bridge over the lock also prevented any great splaying out of the wing walls.

In reference to the general question it may be observed, that the foregoing examples resolve themselves into three classes, viz., dry, or graving docks, wet, or floating docks, and building slips.

Plate 7, Fig. 15.—With examples of the first class, viz., the dry, or graving docks, the great desideratum appears to be, to get them placed at such an angle to the course of the tide, that ships may be docked upon the flood with the greatest facility. There exists but one opinion, among persons acquainted with the practice of docking ships upon the Thames, as to what this direction should be, viz., an acute angle to the flood, or, in other words, pointing upwards; some recommending (if the site will allow it) a direction nearly up and down the stream, others an angle of about 45°, with a dolphin half the length of the ship, above the entrance, to keep her from tailing on the ground if the wind should be on-shore. It is obvious, that the greater the degree of obliquity, the more the river frontage will be required for each entrance. Ships are usually docked head first, and turned out stern first, from dry docks. If the line of direction of the dock points downwards, and forms an obtuse angle with the direction of the flood coming up, or is even square to it, considerable labour and difficulty are involved, in heaving down the stern of the vessel against the tide, so that she may be in a line with the dock. This very force of the tide is taken advantage of, and assists in placing the ship in a proper position, when the dock points up the stream. This direction is equally advantageous in undocking vessels from dry docks, as the almost invariable practice is to turn them out stern foremost; thus the vessel's quarter first meets the tide, is carried upwards, and her bow is brought against the tide in the most convenient position for mooring her.

Plate 7, Fig. 16.—With wet, or floating docks, the case is altered, as regards undocking, and this has been met by the greater width at the entrance, formed by the spreading wings on either side. The circumstances attendant upon a ship entering are precisely the same as when approaching a graving dock; but in undocking a loaded vessel from a wet dock, she is brought out head first. If the entrance pointed up the stream, the vessel's bow would require to be kanted up immediately she met the tide; this would cause considerable inconvenience to an outward bound vessel, which should swing with her bow downwards. Ships are frequently taken out with their sails set on a fair wind, and in such a case, a fault in direction would be still more severely felt.

A direction nearly square to the stream is recommended by some

authorities as the best for wet docks; others recommend an acute angle of about 60° with the flood, as shown in Fig. 16. The amount of this angle, however, becomes of less importance, if a great width is obtained at the entrance, by rounding out, or splaying the wings. The upper wing, or pier head should be formed to a flat curve, or even a straight line, so as to present a favourable angle to the tide, for a ship entering, The lower pier head, or wing, should be rounded, or splayed off very much, to admit of a vessel, whilst going out, turning with her head upon tide; it should also project about 30 or 40 feet further out than the upper pier, in order to cover the entrance and render it more accessible.

The great variations that exist in the examples on the Thames, are attributed by persons interested in shipping, to the importance of the subject never having been sufficiently considered, and also to want of capital and available space on the banks of the river. The positions of dry docks have, no doubt, in many cases been regulated, irrespective of any other considerations, simply by the particular arrangement of the ground in which they have been constructed, the direction of the first dock regulating that of its successors, which were built parallel to it.

The great desideratum with docks of each description appears to be, to obtain as great a width as possible at the immediate entrance, and the larger this is, of less importance does the angle become. The width is considered by many shipwrights as the most important element of consideration; with a great width, a small amount of heaving on one purchase, or the other, will correct a great amount of error in direction. A ship, when being docked at such an entrance, first touches the upper pier, and her stern must then be drawn down, to bring her in a line with the entrance; the greater the width therefore, the better angle for leverage, or purchase, will be obtained. It is also a great desideratum to afford plenty of room to pilots, whether they happen to be taking vessels into, or out of wet docks.

As regards building slips; their direction appears, like many instances of graving docks, to have been influenced, on the banks of the Thames, and perhaps also on other rivers, by internal local circumstances connected with the tenure and division of properties; the construction of one slip has also governed the direction of those in the immediate vicinity, which are generally parallel to the first. This direction, it will at once be seen, cannot be so important as in the instance of graving docks; still, however, as vessels are launched stern foremost, and usually about the same period that admittance

into graving docks takes place, the same reasons that influence the direction of one would affect also that of the other: that is, a vessel being launched, and her stern carried up, her head would be brought up against tide, which is the most convenient position for mooring her, consequently a position slightly inclining up the stream, appears desirable; practically, a direction square to the stream answers the purpose, and is the best, having reference to the value of a river frontage.

The directions herein referred to as apparently the most desirable, are, an angle of about 45° pointing up the stream, for Graving Docks,—an angle of about 60°, in a similar direction, for Wet Docks,—and a right angle for Building Slips.

No one knows better the importance of the subject than the shipwrights and pilots, and with how much less risk vessels may be docked at some establishments than at others. The operation of docking a valuable ship, with perhaps but very few inches to spare, is at all times a nervous process, and they who are in the constant habit of conducting such operations can give the best practical opinions on the subject.*

---

* The opinions of Mr. Dowson, Mr. Knight, Capt. Bond, Capt. Evans, Mr. Kinipple, Mr. Green, Mr. Haslip, and Mr. Wigram are given in letters to Mr. Redman, from whence the following extracts are made:—

Mr. Dowson says:—"I have read with some attention your remarks on the several wet and dry dock entrances on the River Thames, and also examined the sketch you sent me (Fig. 16, Plate 7).

"I feel a strong conviction that a great error has been committed in the construction of most of them. My opinion is, that the entrance should stand in a line, nearly up and down the stream; so that when a ship comes alongside the jetty, for the purpose of docking, the bow would easily enter, and much time and labour be saved in heaving the stern down, against the flood tide.

"The entrance into my dock and Duke shore are both very bad, and the evil is increased by the flood tide running particularly strong.

"I admit that, in wet docks, where the entrances, or jaws outside the dock gates, are generally so wide, the evil is not so severely felt; but I remember when the West India Docks, Blackwall end, were first made, the danger for loaded ships was so great, that it was found necessary to extend the upper pier in the manner I prefer.

"I attribute the bad entrances to want of judgment, want of capital, and perhaps of space on the shore of the Thames."

Mr. Knight says:—"With reference to the general question, I think it may be presumed, that the entrances to the public dock establishments have been constructed in a manner deemed most eligible (having reference to the set of the tide), for the purpose of docking loaded ships, and that the construction of the graving docks has been more particularly determined by internal considerations, as regards the ground on which the docks have been formed, although the entrances to the public docks may, in some cases, have also been influenced by similar considerations. As regards graving docks, it is to be

The Paper is illustrated by a series of diagrams of the forms of the Dock Entrances in the Port of London, from which Plate 7 is compiled.

---

observed, that they are comparatively but seldom used, and that the slack of tide is generally taken advantage of, to dock the vessels.

"The entrance to the East India Docks, pointing upwards to the stream of tide, is probably the best direction which could be given to it, as the stream of tide runs rather strongly across it, and until the introduction of steam tugs, large vessels would occasionally hang, until the tide slacked; now by means of a quarter-rope, the stern can be hove down the stream, when the head is pointed to the lock, and the vessel brought into the line of direction of the lock, without the vessel being brought to a right angle with the stream.

"The following are the observations I have received from Captain Bond, of the East India Docks, and Captain Evans, of the West India Docks.

"Captain Bond says:—'I think the East India Dock entrance has an advantage over the other docks, in having plenty of room in the river, and the tide never running hard, except when it blows with an easterly gale; and now we have the use of the tug to keep the ship's stern down, we can dock immediately we have water; before we had tugs, if the wind blew hard, the large ships would hang until the tide slacked.'

"Captain Evans says:—'I am decidedly of opinion, that the Blackwall entrance into the West India Dock, is by far the best constructed in the port of London. Its bell mouth giving sufficient room to kant the largest vessel that ever was docked in the port, and that without the assistance of either a quarter-rope, or that of a steam-boat, although it must be admitted, that the length of the lock is in some measure an impediment to the quick dispatch of business. Had the basin been carried about 70 feet further out, and the bridge kept within the lock-gates, I should then consider it a perfect model for an entrance, and I am of opinion, that all dock entrances should rather incline upwards with the set of the tide, which would make them easier of access upon the flood, as all vessels of any magnitude should be brought with their head upon tide, to enter with safety, where there is a strong current; but where an entrance is formed in an eddy, or counter tide, which is to be found in various parts of the Thames, I would recommend, that the lock should be placed at right angles with the flood, in the stream; and when there is a strong tide immediately across the entrance, it should incline upwards, with the lower pier-head carried about 25 feet, or 30 feet further into the stream, than the upper one, as that would cause a partial eddy, and thereby make the entrance easier of access, as well as facilitate the docking.'

"The great width of the Blackwall entrance of the West India Docks is advantageous, as regards the undocking, as it admits of the inward vessel being within the entrance, and leaves sufficient room for the outward ship to pass out. In this respect the Shadwell entrance of the London Dock may possess the like advantage."

Mr. Kinipple says:—"I have long paid attention to the different entrances into the various wet and dry docks on the banks of the river Thames, and consider, that an angle of 45°, pointing up stream to the set of the tide, is in every way the most eligible; for instance, Limehouse Bridge Dock, which I now superintend, from being nearly at right angles to the stream, and from the set of the tide being so strong, particularly at the height of the springs,

Mr. REDMAN begged to acknowledge, and to offer his thanks for the assistance afforded him, by the proprietors of docks and the officers of the dock companies on the river, and he requested it might be understood, that when he had designated a dock entrance as "bad," or "indifferent," it was not meant invidiously, but that from circumstances, or locality, it was not so favourably situated as others which he had especially denominated as "good."

He then referred to the drawing of the Blackwall entrance of

---

when it is usual to dock large ships of heavy draft of water, it is very difficult to square the vessels and to place them in position, without a large warp from their quarter, to heave on, with a great number of men, assisted, within the last few years, by steam power. This process causes so much delay, that the vessel frequently cannot be hauled a-head, until nearly high water, and then sometimes with only from three to six inches water to spare. This, it will at once be seen, involves great risk, indeed so much so, that I could name several ships that have grounded in some dock entrances, and have overhung the cill of the gates from 20 feet to 50 feet, owing entirely to the above causes. These difficulties would be entirely obviated, if the docks were excavated to the above named angle, because the pilot could keep the ship off in deep water, opposite the dock, until fifteen or twenty minutes before high water; and when ordered to bring her to (having every rope already prepared), he would be enabled to make more certain of getting her safely in and secured, than at present, when so much labour and care are required.

"With regard to wet docks, I consider nearly the same angle to be equally advantageous, for bringing to and docking a large number of homeward bound ships, in one tide; but with this difference; for undocking, the lower pier-head would require to be carried out nearly at right angles, projecting about 40 feet or 50 feet, and rounded off; which would so widen the entrance, that ships when being undocked, when they always come out head first, may, provided they want to go down the river, that is to say, being outward bound, make a warp fast to the said pier-head, and with another taken off to a buoy, laid out for the purpose, at some convenient distance, be enabled to swing with the tide, and at once proceed on their destination."

Mr. Green says:—"I have no hesitation in stating, that the entrances of dry and wet docks should point up, and not down the stream."

Mr. Haslip says:—"My opinion is, that dry docks pointing up the stream, on the river Thames, at an angle of 45°, may answer every purpose.

"With respect to wet docks, I consider that they ought to be at right angles, with a sufficient entrance.

"Respecting building slips, the angle, or run, is always governed by the river wherein a new ship is about to be built and launched."

Mr. Wigram says:—"I fear you will not arrive at any definite rule on the subject, but it appears to me, that all dock entrances should point upwards; the degree will depend on whether the tide runs strong, or not, at the point, or part, where the dock is to be constructed. You are of course aware, that the set of the tide alters greatly in velocity, at different parts of the river; but, in my opinion, the stronger the set, or run of the tide, may be, across the dock entrance, so much more should it point up, for the convenience of using the dock."

the West India Docks (Fig. 2, Plate 7) and stated, that there vessels could not be brought in so readily as had been originally intended; but they were brought up head upon tide, and were warped in; also to the Shadwell, or lower entrance of the London Docks, (Fig. 11,) which although pointing down the river, and forming an obtuse angle with the line of direction of the flood, was yet, by the additional works at the entrance, resolved into a very advantageous form; for the upper wing, with the timber jetty and dolphin, formed a rather acute angle with the particular set of the flood, and was therefore advantageous for docking vessels; the lower works formed at the same time a good direction for vessels departing, and being brought up head upon tide. Viewing the particular outlines of the London Docks, it was obvious that a direction pointing up the stream would have entailed so bad an angle of communication with the docks, and so awkward a turn for the vessels, as to render such a position next to impossible.

Fig. 14 was a plan of the St. Katherine Docks' entrance, where the direction, as had been before explained, was rendered of less importance by the great depth of water which allowed vessels to be docked after high water. At such a site as this, a wide entrance was almost unattainable, from the great value of the land.

Figs. 15 and 16 were drawings of what appeared from evidence to be good forms for entrances; the former for a graving dock, at an angle of 45°, with a projecting pier on the lower side, and the latter for wet docks, at an angle of 60°; the upper wing turning at an angle of 45° upwards, and the lower at a similar angle downwards, together with a protecting pier. Such an entrance would afford equal facilities for docking and also for undocking; a double lock was also shown.

There was another question which, however, had not been touched upon in the paper, viz., the best angle for a wall, along which a vessel would pass to enter a lock; for instance, upon a canal, what angle would give the least amount of resistance to a boat entering a lock? this, however, was not of importance, in reference to the present inquiry, still it was an interesting question, well deserving the attention of the Institution. To illustrate the remark as to docking vessels, he might remark, that at Messrs. Young's establishment at Limehouse, where a large Government steam frigate was now being fitted, it was found necessary, in docking that vessel, to connect a warp from her starboard quarter to a capstan at the West India Dock, in order to keep her in position, on account of her great length.

Mr. WALKER praised the talent and industry displayed by Mr. Redman, in collecting the examples shown by the drawings; the majority were matters of fact, and the compiled drawings (Figs. 15 and 16) were theoretical examples, deduced from reasoning upon the facts now laid before the Meeting; it must be borne in mind, that from the value of land in the vicinity of London, and more particularly of river frontage upon the Thames, the direction of the entrances must have been, to a great extent, regulated by local circumstances. For instance, the Shadwell entrance to the London Docks could not have been differently placed, because, from the position of the docks, any other than a direct entrance would have created greater inconvenience than any facility of entering could have compensated for. At the same time, from a local eddy, there was slack water in front of the entrance.

The entrances to private docks were even more governed by locality, and the influence that might be exercised upon the neighbouring property; because in the case of an oblique entrance, the vessels in entering or leaving the dock, would traverse and occupy the frontage on either side of it. There was no doubt of the theoretical correctness of making the entrance to point obliquely up the stream, if it was situated in the run of the tide, and the locality permitted it; but where there was not any run of tide, or an eddy existed, or where a deep fore-bay could be formed, the entrance might be quite as advantageously placed at right angles with the stream. It must, however, be considered, that in entering, when a vessel came up with the tide, it made fast, and then swung; in the case of the right angle entrance, the tide striking upon the broadside would have a tendency to drive it upwards, whereas the tide striking a vessel obliquely, would have less power upon it, and less force would be required to draw it across the tide into the dock. When the mouth was widened, and was shaped as in Fig 16, the current would assist a vessel, and with a judicious arrangement of buoys, vessels would be docked very rapidly; and in such cases, if the locality permitted, the angle pointing upwards was advantageous; but where still water existed, from a bend in the river, or the tide was sluggish, a rectangular entrance would be found as useful, and in general would accommodate itself better to the property upon which the dock was situated.

Mr. RENNIE thought the author had taken very judicious views of the subject; it was, however, evident that engineers must be governed by local considerations, and the velocity of the tide. The late Mr. Rennie had designed several entrances pointing up the stream, and with the widened mouth like Fig. 16; but in practice,

it had been found necessary to adapt them to the locality, and with reference to the adjoining properties. Mr. Rennie had arrived, by calculation, at certain results, and had determined, that an angle of 45° pointing upwards was the best for a dock entrance.

Mr. SIDNEY YOUNG felt that it would be ungracious on his part were he to withhold, on the part of those whose avocations, like his own, would make them practically the recipients of the benefits to be derived from such a discussion as the present, his best acknowledgments to his friend, Mr. Redman, for the careful investigation he had undertaken, and to the meeting for the attention that had now been given to the subject.

To all the remarks and suggestions he had heard from Mr. Redman, in reference to the most convenient "angle to the flow of the tide" for placing dry docks, he gave his unqualified concurrence; nor did he think that any one who had opportunities of forming a practical opinion on the subject, would for a moment question their correctness. No better evidence of the important service now rendered could, he thought, be afforded, than the great variety of the angles formed by docks in the Thames, as so ably exemplified in Mr. Redman's diagrams, proving, as it appeared to him, that this question, important as it was, had hitherto engrossed very little attention. The constructors of these entrances were, in many instances, probably too much restricted by local circumstances to allow of their placing them at so acute an angle as was now proposed; still, in the instance of dry docks, they might in almost every instance at least have adopted the same direction, with an angle so small as not perceptibly to affect the general distribution of the property. This would frequently increase the facility of moving vessels into and out of dock, especially in those situations which were exposed to a particularly strong set of tide, to an extent that could scarcely be appreciated by those who were not in the constant habit of superintending such operations.

With respect to the entrances of wet docks, the opinion of an experienced pilot should be held of more value than any other; but he was led to believe, from the remarks made by some gentlemen present, that the subject had been too much regarded as though vessels had only to be docked, and not just as often undocked whilst loaded. For the first purpose he was still of opinion, that Mr. Redman's plan was equally applicable as to dry docks; but, as undocking had also to be considered, he thought, practically, a right angle might be found sufficient, with a lower wing boldly splayed out, as in Fig. 16, which frequently afforded the pilot an opportunity of setting sail before meeting the tide. Without such a provision

the vessel's head would be carried up the stream, and the necessity of swinging her round would be involved. This would at all times be attended with great inconvenience, and, in comparatively contracted navigation, with much risk. In all cases Mr. Redman's proposed dolphin on the upper side would undoubtedly be most advantageous. In reference to H. M. steam frigate "Termagant," now in their establishment, it was true that, from her great length and the slight acuteness in the direction of the dock, the action of the flood presented great impediments to placing her in position, and afforded, therefore, a powerful illustration of the advantages that might have been derived from Mr. Redman's proposed conditions for the directions of docks, and the addition of the dolphin, which would have prevented her being carried up "fore and aft."

Mr. T. B. SPENCE confirmed the statement relative to Messrs. Tebbutt's establishment, Limekiln Dock, and the general views of the Paper. In their yard, a dock pointed up in nearly the direction proposed by Mr. Redman for dry docks, and it was found, that ships were easily docked in it, with a moderate number of men; certainly with more ease than if it were at right angles to the stream. It was probable that the direction of this particular dock had been more influenced by the conditions of the property, than the fact that such a direction was the best for docking; and he explained, as the reasons for the direction, that it had been formerly a building slip, and the position of another dock had induced this particular direction to get greater length. Pilots had always found, that when ships were launched from it, they had been easily brought head upon tide. Since it had been deepened and altered into a dock, it had been found, that ships entered easily, and in going out came almost directly head upon tide. Where the form and position of the yard would admit of it, a direction pointing up the stream increased the facility of docking, and was, therefore, to be recommended for a dry dock. The conditions of the property would not, however, always admit of this; but the introduction of steam power had lessened the inconveniences attendant upon docks at right angles to the stream, more so, however, in some cases than in others.

As regarded wet docks, Mr. Spence stated, that a direction pointing upwards, likewise facilitated the introduction of loaded vessels; but that he considered a pilot the best authority on this subject; that, for undocking, it was necessary that the lower pier should point down, as was provided for in Fig. 16; as, unlike ships coming out of dry dock stern foremost, and therefore readily swinging head upon tide, ships came out of all wet docks head foremost;

consequently, unless the lower wing pointed downwards, the ship's head, in coming out on the flood, would have a tendency to drift upwards, instead of coming round head upon tide.

The dock in their yard which had been referred to, was rather embayed, as a reference to a map of the river would show; this increased the facility; but still he was strongly of opinion, that the convenience attached to it was chiefly due to its direction in reference to the stream. One great object in forming the entrance to a wet dock, was to have it sufficiently wide, with diverging piers, so that when the ship was sheered to, her midship part might come against the upper pier, whilst her bow was at the lower side; she would thus enter readily. For this reason the direction of the lock did not appear to him so important as the form of the outer entrance. The Shadwell entrance of the London Docks, since the addition of the timber jetty on the upper side (pointing upwards), had acted admirably. Viewing Fig. 16, a practical difficulty might present itself, viz., of entering one ship while another departed; but this was seldom, if ever, attempted. The outward bound vessels generally left, as soon as there was water for them, and homeward ships did not generally get up until towards high water. If a loaded ship came up, whilst another was going out, she was obliged to keep out of the way of the entrance until the outward bound vessel was clear.

Mr. CUBITT, V.P. said, the object was to get as many vessels as possible in and out at high water, in order to take advantage of the depth of water and the slack tide, which rendered less power necessary. For the purpose of obtaining still water, a deep and capacious fore-bay was sometimes made, as it was found materially to facilitate the entrance of the vessels; and whenever the locality permitted the formation, and means could be adopted for preventing it from silting up, it should be adopted. The examples which had been brought forward by Mr. Redman were useful, showing as they did, that although the trade of the port was carried on, practically, with efficiency at all the docks, still from the particular direction and conformation of some entrances, ships were docked and undocked much more readily at some, than at others.

Mr. MAY drew attention to the entrance of the Ipswich Docks, constructed from the design of the late Mr. H. R. Palmer, and where he had free scope to do as he pleased; yet he had designed it at an angle pointing down the stream, like the Shadwell entrance of the London Docks. This appeared contrary to the received opinion, and yet the work was very successful and answered the purpose perfectly. The entire width of the river, at high water, was about

150 feet, and the entrance was so placed, that a vessel coming up with the tide went directly into the dock without swinging.

Mr. WALKER said, it must be evident there were practical difficulties occasioned by a downward direction being given to an entrance; they were, however, in some degree compensated for, by the formation of a deep recess or fore-bay, in which a vessel would be out of the run of the tide. This gave great facility for docking a vessel, which under all circumstances was a somewhat hazardous operation. In the case of Ipswich, it appeared that there was a certain difficulty to contend with, and, like a skilful engineer, Mr. Palmer had chosen the simplest method of overcoming it. In so narrow a river, it would have been difficult for the vessels to have swung, and therefore he preferred their entering directly into the fore-bay, in doing which they would be aided by the tide.

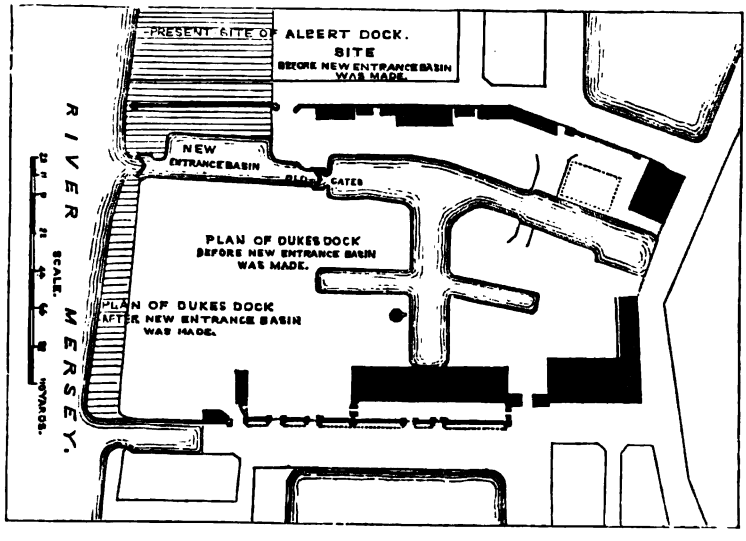
Mr. MURRAY said he had discussed this matter, at some length, with Mr. Walker, when examining the plan for the proposed docks at Sunderland, and being guided, in a great degree, by the opinion of the shipowners and pilots, it was settled, that the entrance should be placed acutely up the stream, and that the exit should be the reverse. It was a great object at Sunderland, to enable as many vessels as possible to enter and to leave the port on the tide; for which purpose a tidal basin of three acres in extent, with tide-gates, was intended to be constructed, for the vessels to enter and bring up in; from thence they entered through wide gates into the main dock. The tidal basin became in fact a great lock. The object was to get from three hours to three hours and a half for docking vessels, on each tide. In the Thames, from ten to fifteen minutes were occupied by each vessel, in passing a lock, so that the amount of accommodation was in fact restricted; but in other places, where the system he had described was followed, greater facilities were afforded. For instance, at Hartlepool, he had counted fifty-five vessels leaving in a tide, and he had heard of seventy vessels leaving in the same time. The forms of widened entrances, shown by Mr. Redman, approximated to the system Mr. Murray had recommended; he would present to the Institution a description and plans of the dock at Sunderland, as soon as the works were completed.

Mr. REDMAN remarked, that in the case of the Ipswich Docks, the particular direction was obviously entailed by the peculiarities of the site. The entrance was from an artificial cut, which was so narrow as not to afford space for swinging; and the entrance was, as Mr. Walker had explained, away from the channel, in an artificial recess, or fore-bay, which created dead, or slack water, and neu-

tralised, to some extent, the effect entailed by an obtuse angle with the line of flood.

Mr. CUBITT, V.P., quite agreed, that however desirable it might be, to place the entrance pointing upwards, as had been suggested, and had been so frequently and successfully practised, still locality must in general govern the engineer in laying out his plans, and he must exhibit his skill, not only in the construction of the work, but, if possible, in the selection of a spot where an eddy of the tide, or slack water could be obtained, and which at the same time possessed the other requisite qualities for a dock. Mr. Cubitt had recently put in practice at the Duke's Dock at Liverpool (shown in the wood cut), the system proposed by Mr. Murray for the Sunderland Dock. A pair of gates had been adapted to the entrance of the outer dock, which had thus been converted into a tidal basin, whence the "trows" and other vessels could be passed into the dock with great facility, thus materially adding to its advantages. He believed that principle was generally found to answer, and he would advise its adoption wherever there was an extensive trade.

DUKE'S DOCK, LIVERPOOL.


PRESENT SITE OF ALBERT DOCK.
SITE
BEFORE NEW ENTRANCE BASIN WAS MADE.
NEW ENTRANCE BASIN
GATES
PLAN OF DUKES DOCK BEFORE NEW ENTRANCE BASIN WAS MADE.
PLAN OF DUKES DOCK AFTER NEW ENTRANCE BASIN WAS MADE.
RIVER MERSEY.
SCALE.
YARDS.

Mr. MURRAY exhibited a plan and enlarged diagram of the docks in progress of construction at Sunderland, of which he promised to give a detailed account on their completion. The original intention had been to leave a portion of the old pier, in order to form two entrances; but it was subsequently decided to remove all

the old work, in order to afford as large a space as possible for the vessels to bring up and swing by their anchors, or to be towed by steamers into the tidal basin, whence thirty at a time would enter the half-tide basin and thence into the dock. By these means a very extensive trade could be accommodated, as was indeed necessary, when as many as 150 to 160 vessels required to leave on a tide.

At Hartlepool the lock was not used for passing the vessels; the gates were left open for an hour and a half at the top of the tide, and the vessels were towed by steamers directly into the dock.

Mr. RENDEL, V.P., agreed with the commendations bestowed upon the industry and talent displayed in the Paper; but he did not accord with the opinion, that any general rule could be laid down to suit all cases. Many points required careful consideration; the velocity and rise of the tide, the local currents, an eddy caused by a bend of the river, the width of the channel, the nature of the trade and the size of the vessels, would all influence the plans of an engineer, whose skill and talent should be displayed by his meeting and combating successfully, the natural difficulties. For this reason few entrances were similar, and it was evident, that in practice, it had been found impossible to establish any definite angle. If that were possible, one set of drawings would suffice for all cases, and the exercise of skill and judgment would no longer be required.

Mr. SCOTT RUSSELL confirmed Mr. Rendel's views; the science of engineering had not yet arrived at such definite conclusions, as to enable given rules to be laid down for a subject embracing so many considerations. It was evident from the examples brought before the meeting, and from many others which were familiar to all engineers, that it was not possible to lay down any undeviating principle; but in comparing the examples, and considering local peculiarities, he thought it might be assumed, that a step towards it had been arrived at. If, as was stated, facilities for docking a loaded ship upon the flow of the tide were given, by having the entrance pointing upwards at an angle of 60°, and for undocking a loaded vessel on the turn of the tide, by an entrance pointing at the same angle down the stream, it must be evident, that the wide entrance, with the piers at opposite angles, as proposed in (Fig. 16), would be advantageous wherever sufficient ground could be obtained; and if a deep fore-bay could be constructed, so that it would not silt up, it would afford additional facility, as a vessel in entering would swing and come in, without interfering with a vessel going out. This was only the first step to a tidal basin, which appeared to be a great convenience for an extensive trade. This however presumed that the docks were upon a wide river, and where land was not of very great value; but in a narrow channel, where the stream or the

tide set heavily across the entrance, and where the value of the land on the banks was as great as in London, even that rule could not be observed, and the engineer must be guided by local considerations, in order to afford the greatest amount of facility at the least cost.

Mr. REDMAN expressed his regret, that Mr. Rendel had not been present when the paper was read, and that he had only partially heard the discussion upon it. It had certainly not been his intention to assume, that there were certain angles for dock entrances, applicable to all sites; on the contrary, he had distinctly stated, that all the circumstances of position, set of tide, &c., must be carefully attended to. The examples he had given for proposed entrances, were intended as examples of combinations of the good qualities of the different entrances on the Thames, and were laid down in accordance with the opinions generally entertained in the port of London, among ship-builders, pilots, and dock-masters, whose practical opinions upon such a subject were, he conceived, well worth attention. These examples, therefore, were only recommended where the site and the set of the tide would admit of such constructions. Neither did he understand the tone of the discussion, to lead to the conclusion, that one angle was suitable for all situations; for, on the contrary, the different attendant circumstances appeared to have been considered by the various speakers.

He could not agree with Mr. Scott Russell, that possessing a well formed fore-bay, the direction of the lock, or inner portion of the entrance, became of minor or secondary importance. It was necessary, having the upper wing pointing upwards at the angle shown, that the lock should be in the same line, in order that the vessel might be easily drawn in. Mr. Russell had also fallen into error in assuming that a vessel was undocked upon the ebb; if that were the case, the direction of the lower wing would be unimportant, as immediately the vessel's bow met the tide she would swing round into the desired position; such however, was not the case, as vessels were undocked upon the flood, and it was necessary to form the lower wing in such a manner, that by means of the warps attached to her larboard bow, as she left the entrance, she would be brought head upon tide, and swing in the requisite direction. If the lower wall pointed considerably up the stream, the labour in counteracting the tendency of the tide, and hauling her bow down stream, would be much increased. It might likewise be observed, as Mr. Russell had instanced, that a position where the tide set very strongly across the entrance, was the exact site for which such an entrance as that shown by Fig. 16, was adapted; the reasons for this had before been given, and were, in his opinion, quite obvious.

Mr. BRUNEL accorded generally with the views expressed by Mr.

Rendel; he thought, however, that although the Institution might not be able to fix any rules, or principles, which would evidently have an injurious tendency, the meetings were extremely useful, in making the profession better acquainted with what had been done, and in affording opportunities for discussing the principles of construction and the results of certain works.

It did not appear, that any dock entrances had been actually constructed of the form and at the precise angle laid down in Fig. 16; now there did appear to him certain disadvantages, attendant even upon that plan. Suppose, for instance, a rapid flowing tide, with the wind setting directly up the stream and across the entrance; he apprehended there would be much difficulty in bringing the vessel to, swinging her and hauling her down into the entrance. Therefore, wherever from the prevalence of certain winds, such a combination of circumstances would be liable to occur, no engineer would think of employing that particular form; but would endeavour to find a position for the entrance where an eddy existed naturally, or he would form a fore-bay to produce still water, in order to facilitate the entrance of the ship. It appeared also to him, that there would be considerable difficulty in bringing a vessel so directly against the tide, upon leaving, as was proposed. The examples that had been given were undoubtedly useful; it would, however, be dangerous to assume, that they afforded sufficient data, whereon to base arbitrary rules, for cases which, to superficial observers, might appear identical; but the civil engineer, whose province it was to examine, and weigh maturely, all the considerations involved, would see at once, that every case must differ, and his skill and experience must be exercised, in meeting and providing for all the local difficulties. It appeared therefore certain, that in this, as in almost every other branch of engineering, no arbitrary rules could be laid down to meet all cases, and the civil engineer must be guided by his scientific and practical knowledge; the great use of examples being to enable him to avoid a repetition of the errors which had been found to exist and to cause certain inconveniences in works previously executed.

Mr. REDMAN, in answer to Mr. Brunel, said there was no entrance on the Thames of the exact form laid down in Fig. 16; but such a fact would not, he conceived, be urged as an objection against its adoption where circumstances would permit it; many entrances on the Thames possessed some of its individual features, for instance, the lower wing of the Shadwell entrance of the London Docks (Fig. 11,) and the upper wing of the Blackwall entrance of the West India Docks (Fig. 2); there were also numerous examples, shown in Plate 7, where vessels were

docked and met the tide, when leaving in the manner proposed. The consideration of the occurrence of a rapid flood, with the wind setting up, induced him to give the preference to an angle pointing up stream, as being most available under such circumstances, and he believed that to be the general opinion of persons well acquainted with the system of docking vessels in the Thames. It was true, however, as had been shown in the Paper, that diametrically opposite opinions had been entertained, which had induced constructions very different to those now proposed, but which, by the addition of supplemental outworks, resolved themselves very nearly into the form laid down in Fig. 16. The object in pointing the lower wing down stream, was to bring a vessel, when departing, head upon tide. It had been already shown, that there were numerous examples in the Thames, where vessels when outward bound, met the tide at a great disadvantage, from the lower wing not affording such requisite facilities; a vessel leaving such an entrance as that under consideration, with a warp attached to her larboard bow, swung immediately into the requisite position, but if the entrance pointed up, or was even square, she would have to swing completely round with a chance of tailing upon the ground; he could not understand the objection to the proposed forms, which he thought had been misunderstood, and if a vessel could not arrive in, or leave an entrance so formed, upon a river circumstanced like the Thames, it was difficult to imagine the particular conformation which would provide the requisite facilities. The fact of laying down general principles for cases of engineering such as these, founded upon the experience of the past, due consideration being given at the same time to all the attendant circumstances, would not, he conceived, lessen the duties of the engineer, as the variations in the level, the site, the foundation, and the construction, would still demand the exercise of his judgment and experience, as well as his constant services, as heretofore.

March 7, 1848.

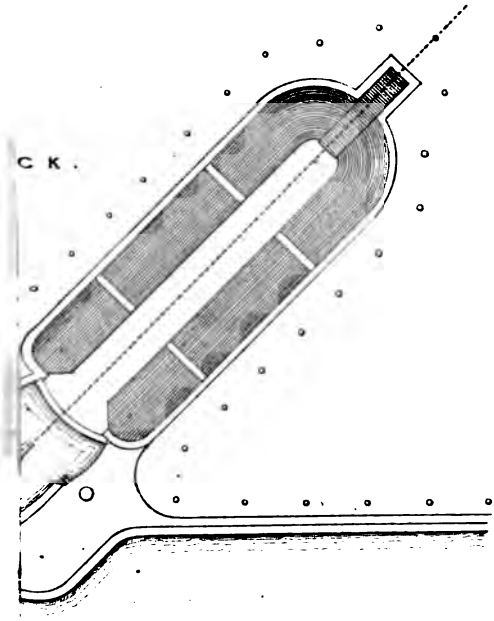
JOSHUA FIELD, President, in the Chair.

The following candidates were balloted for and duly elected:—

William Baker, John England, Samuel Clegg, Jun., James Elliott, and Henry Fowler, as Members; and Edward Adams, Edward Hughes, George William Harris, Stephen William Leach, Alexander Drysdale, Robert Rawlinson, Frederick Ransome, and George Henry Saunders, as Associates.

The discussion on the Paper (No. 777) "On the Forms and Positions of Dock Entrances, situated upon a Tide-way," by J. B.

Fig. 15.



Redman, Mem. Inst. C.E., occupied the whole time of the meeting, to the exclusion of any other original communication.

Mr. John Chubb (St. Paul's Churchyard,) exhibited and described an Iron Chest, constructed by him, for the transmission of money and valuables on Railways.

A wrought-iron chest (Figs. 1, 2, and 3), lined throughout with

Fig. 1.

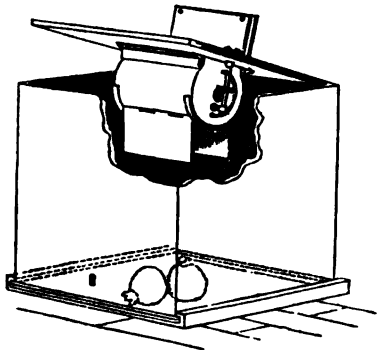


Fig. 2.

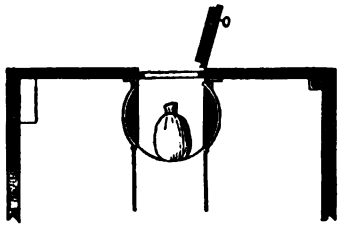
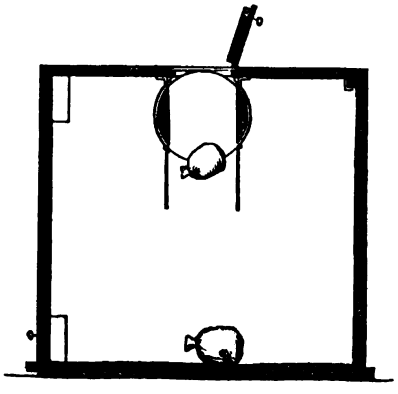


Fig. 3.



hard steel plates, is locked down, at the terminus, to a strong iron-plate fixed in the Guard's carriage. The key of this lock, and also the key by which access can alone be obtained to the interior of the chest, is kept at the principal terminus, by the officer who has charge of the cash.

Each Station-master is provided with a key, which opens a small lid at the top.

When he has money, or small valuable parcels to send, he unlocks the small lid, places the bag of money, or the parcel, in an open drum underneath (Fig. 2), moves a handle which turns the drum, and the cash is dropped inside (Fig. 3). He must then move the drum back to its place and see that the money has fallen into the chest, before he can shut the lid and take out the key. Thus it becomes impossible for him to leave the lid unlocked.

When the chest arrives at the terminus, it is unlocked from the frame, taken into the office and placed on a similar frame, to which it is locked down. The cash-keeper only, can with his key, obtain access to the money, and unless great violence be used, the chest cannot be removed from its position.

This kind of chest has already been found very useful, in the prevention of robberies, and in insuring the punctual transmission of cash from the various stations on several railways.

March 14, 1848.

JOSHUA FIELD, President, in the Chair.

No. 782. "Account of the Effect of the Storm of the 6th of December, 1847, on four Sea Walls, or Bulwarks, of different forms, on the coast near Edinburgh; as illustrating the principles of the construction of Sea Defences."* By William John Macquorn Rankine, Assoc. Inst. C. E.

There are few branches of engineering with respect to which greater uncertainty and difference of opinion exist, than that of the construction of sea walls and breakwaters.

The question has been frequently before the Institution, and in its archives there is much useful information on the subject.

The valuable paper of Lieutenant-Colonel H. D. Jones, read in 1842,† may be particularly referred to, as its conclusions are to a

---

* The discussion on this paper was extended over portions of three evenings; but an abstract of the whole is given consecutively.

† *Vide* Minutes of Proceedings, 1842, vol. ii., p. 124.

certain extent verified, by the facts which have come under the author's observation.

Conceiving that every addition, however small, to the facts recorded respecting the efficiency of such works, must tend to bring the principles of their construction nearer to certainty, the author felt it to be his duty to lay before the Institution, transverse sections (Plate 8) of four sea walls, upon a portion of the coast of the Frith of Forth, near Edinburgh, having an exposure towards the north and north-east, and to give an account of the effect upon them, of one of the most violent storms on record in this climate, which took place on the 6th of December, 1847.

Figs. 1 and 2, Plate 8, represent the sea wall of the Leith branch of the Edinburgh and Dalkeith railway, which was completed in the winter of 1837. Fig. 1 is the transverse section, as originally designed by the consulting engineer, Mr. Walker. Fig. 2 is the transverse section, as the wall was actually built.

The author was resident engineer of the railway whilst this wall was executed, and it is the only one of the four walls, the formation of which he can describe from actual inspection, during the progress of the work; the other three sections are, therefore, to be regarded rather as giving the external form, and the general style of building of the walls they refer to, than as affording minutely accurate information respecting the details of their construction.

The deviations from the original design and specification were chiefly in matters of detail, and will be apparent on an examination of the two sections. The most important were the following:—

The hearting was composed of concrete, instead of rubble.

The parapet was omitted, as no bulwark of ordinary height could have kept off the spray, which sometimes rises 20 feet above the wall.

A small wall was added at the landward side of the embankment, so as to retain the sand in a sort of trough; for, until this was done, it was found that the spray, collecting in pools on the surface of the embankment, after a gale, washed away the material in large quantities; but after the formation of the trough, the water subsided by filtration through the sand, without doing any damage.

As boulder stones were abundant on a neighbouring part of the beach, they were used to form a nearly horizontal pitching to secure the foundation against being undermined, instead of using the sheet piling shown in the section, Fig. 1.

It was found, from the effects of a violent gale which took place during the progress of the work, that the coping stones, which weighed about half a ton each, were liable to be lifted by the sea,

thus exposing to destruction the courses of smaller stones beneath them. They were therefore connected together by cylindrical cast iron dowels, 1¼ inch in diameter, and 12 inches long, placed in the line of the centre of gravity of the stones, and penetrating 6 inches deep into holes made to fit them, in each stone. This mode of connexion has answered its purpose perfectly, not a single coping stone having been lifted by the most violent storms.

With the exception of the alterations and additions just mentioned, the wall was executed almost exactly according to the original design of the consulting engineer.

The total length of the wall is about 750 yards, and its height is 13½ feet above the beach, at the most exposed part, diminishing to about 6 feet at the ends; this gives only 4 feet above the level of high water of equinoctial spring tides. The least thickness is 5 feet, the greatest thickness is 10 feet: the back of the wall is vertical; the face has a batter of about 5 inches in a foot, at the lower part, and towards the upper part it becomes curved, and overhangs slightly at the top.

The whole of the masonry is of white sandstone from Craigleith quarry. The foundation course is composed of large flat stones, 12 inches thick, laid horizontally, at an average depth of 4 feet below the surface of the beach. The stratum on which it rests is clean sea sand, with a slight mixture of fine gravel; firm when the tide is low, but when saturated with water, it is so moveable that the author has found stakes, which had been driven 2 feet deep into the beach to mark the line, shifted during a stormy night 3 feet from their former place, without losing their vertical position, or rising out of the sand; yet the foundation of the wall has never shown the slightest symptom of insecurity. This is one amongst many instances of the safety of a foundation on pure sand when it has no outlet to escape laterally.

The face of the wall was built in courses, from 6 inches to 12 inches in thickness, of squared hammer-dressed stones, averaging 2 feet in depth; the back was built of coursed rubble, averaging about 18 inches in depth, and the interior was filled with concrete, composed of gravel from the beach, laid in courses 12 inches in thickness, as the masonry was finished. There are two courses of bond stones as shown in the section. The coping stones are 14 inches thick, and average 3 feet in length.

At first, the joints of the face were protected, by scraping out the mortar for a depth of 2 inches, and pointing them with cement; but as it was found, that the sea sometimes broke off and extracted large pieces of the cement, even after it had set, it was considered advis-

able to lay the remainder of the face stones in cement, for a depth of 4 inches inwards, whilst building the wall.

In order to promote the accumulation of sand and gravel at the base of the wall, several timber groynes, formed of planks set on edge between a double row of piles, were placed at right angles to it.

The whole of the masonry was constructed by workmen in the employment of the Company, under the immediate direction of Mr. Somerville, upon whom the style of execution reflects great credit.

The gross average cost of the wall was somewhat below twelve shillings per cubic yard.

Almost immediately after the completion of this work, the most violent north-east gale occurred which had been known on that part of the coast for twenty years; but the wall, though exposed to the full force of the waves, did not sustain the slighest damage.

Ten years afterwards, on the 6th of December, 1847, a more violent storm occurred, which damaged, or partially destroyed almost every other sea defence on the neighbouring coast; yet the sea wall of the Leith Branch Railway escaped without injury.

The horizontal pitching at the foot of the wall was alone damaged to a slight extent, by some of the stones being lifted out of their places by the waves; but they were generally deposited near their original sites, so that the necessary repairs could be made at a trifling cost.

The sections (Figs. 3, 4, and 5) represent sea defences between Newhaven and Granton, the foundations of which rest chiefly on shale, or on sandstone, which strata crop out on that part of the coast.

Fig. 3 represents the cross section of a much older sea wall and bulwark, on the turnpike road between Newhaven and Trinity.

As the wall was not breached at any point by the storm of the 6th December, the author is not able to give its thickness, nor the depth of its foundation. The face is nearly perpendicular, and it is built entirely of rubble, laid in mortar, with a pointing of cement in the joints of the lower courses. The roadway is about 8 feet above high water of spring tides, and the parapet rises 4 feet 6 inches higher.

The foundation of this wall is protected by a dry stone pitching, sloping at angles of from 30° to 40°.

The only effect of the storm was, that the upper part of the pitching, at several points, was carried away, to the extent shown

in the section. The vertical wall was not damaged, except at one point, where a fishing-boat being thrown upon the road by the waves, overturned an iron railing, which at that spot filled a small opening in the parapet.

Fig. 4 is a section of the sea wall of a portion of the Edinburgh, Leith, and Granton Railway.

This wall is 2 feet 6 inches thick; its section approaches to the form of a hyperbola. For a depth of about 7 feet below the base of the parapet, it is nearly perpendicular, and has counterforts of the form shown in the section. Below the point marked A, it becomes a dry stone bulwark.

The effect of the storm of the 6th December upon this structure, was to form two long breaches, by which the building was entirely demolished, with the exception of the lower portion of the dry stone bulwark (marked by a darker colour in the section), and several of the counterforts, which were left standing alone.

This result was obviously occasioned by undermining; the stones between the point A and the bottom of the breach being extracted by the waves, the upper part of the wall, having no independent foundation, fell into the sea.

Fig. 5 represents the sea wall of the Edinburgh, Leith, and Granton Railway, at and near Granton.

This is a sloping bulwark of a nearly parabolic form. It is built dry, except the string course and parapet, and consists of stones, which are, as the section shows, much larger and heavier than those employed in building any of the walls previously mentioned, most of those in the lower part of the slope weighing full half a ton each.

The stones of the heavy string course, on which the parapet rests, areconnected by means of a flat malleable iron bar, measuring $2\frac{1}{2}$ inches by $\frac{1}{4}$ inch, laid along their upper surfaces, and attached to the stones by iron spikes $\frac{5}{8}$ inch in diameter.

The coping stones are connected with each other, and with the dado of the parapet, by T shaped iron cramps.

The damage done to this wall, by the storm, was comparatively trifling; it consisted in the overturn of a few yards of the parapet and string-course, and of the dry building immediately beneath; the iron connecting bar being bent and broken.

The efficiency of the surface of a wall to resist the action of the waves, obviously depends on two circumstances; first, the power with which the moving particles of the water act on the stones at the surface; and secondly, the force with which those stones resist removal. The object to be attained is to render the moving power

of the water as small as possible, and the resisting force of the stones as great as possible, relatively to each other.

Without entering into the theory of waves, which involves the highest branches of mathematical analysis, it is sufficiently obvious to daily observation, that the oscillation of each particle of water, in a wave moving freely, is partly vertical, and partly horizontal; that when a sufficient depth of water exists in front of a wall, or a line of cliffs, the mutual action of the direct and reflected waves, produces a series of points of greatest agitation; and that at those points the horizontal oscillation is either null, or so small, as compared with the vertical, that practically the motion of the particles may be considered merely as an oscillation up and down.

A vertical surface is, therefore, that which offers the least possible impediment to the natural motion of the particles of water, under such circumstances, and upon which, consequently, they act with the least power; and a horizontal surface, being perpendicular to the motion of the particles, is that upon which they act with greatest power.

It is also obvious, that when waves encounter a sloping bulwark, or a sloping beach, the vertical part of the oscillation is gradually converted, as the waves proceed, into an advancing and retreating oscillation, parallel to the slope; that being the only direction in which the particles can move, without destroying the surface of the beach, or bulwark; and this oscillation has a powerful tendency to overturn and to remove any obstacle which projects above the line of the slope. Hence it is, that large stones, extracted during storms, from the seaward slopes of breakwaters, have frequently been swept entirely over to the landward side; and from the same cause it also arises, that the coping and upper portions of a curved bulwark, such as that in Fig. 5, are liable to be overthrown, by the concussion of the body of water directed against them, by the lower part of the slope.

The force with which a stone resists removal, is composed of three parts; the first arises from its own weight, and is obviously greater the flatter the slope, and is greatest of all when the surface is horizontal;—the second arises from the pressure of the superincumbent masonry; and this is as obviously greater, the steeper the slope, and greatest in a vertical wall;—the third is the adhesion of the mortar, or cement; and as this depends, to a certain extent, on the pressure from above, it also is greatest in a vertical wall.

These principles appear to be entirely in accordance with the facts which have been narrated.

In such structures as the pitching at the foot of the walls in Figs.

2, 3, and 4, and the lower part of the slope of Fig. 5, the resistance to the action of the waves arises, almost altogether, from the weight of the stones, and therefore increases as the slope approaches the horizontal; but as the moving power, exercised by the particles of water, also increases, it is clear, that the stability of bulwarks so constructed depends altogether on the use of sufficiently large and heavy stones, such as those employed in Fig. 5. Hence, in Figs. 2, 3, and 4, the stones of the pitching not being sufficiently heavy, were partially displaced.

In Fig. 4, the destruction of the slope occasioned the fall of the wall, which rested on it; but in Figs. 2 and 3, where the pitching was not used to support the wall, but merely to protect the foundation, the wall suffered no injury in consequence of its removal.

In Fig. 2, where the pitching was laid on the natural level of the sand, the stones displaced, were deposited near their original site; but in Fig. 3, where the slope was comparatively steep, they rolled down with the receding oscillation.

The walls (Figs. 2 and 3) being vertical, or nearly so, approach the form of section which gives, at once, to the particles of water, the least amount of displacing power, and to the masonry the greatest amount of the resistance, arising from the pressure of the superincumbent materials, and the cohesion of cement and mortar; and they afford an illustration of the stability which may be attained with such a form of section, in a structure built of comparatively small stones.

Owing to the extremely small elevation of the wall (Fig. 2) above the surface of the water, it was necessary that the coping should be sufficiently massive to resist, by its weight alone, any force tending to displace it; but in Fig. 3 such a coping was not necessary, as the top of the wall was above the reach of the action of the waves.

The Author has endeavoured, in drawing general conclusions respecting the construction of sea walls, to avoid going beyond the limits warranted by the facts he has stated. His conclusions may be received with caution, or with dissent; but he trusts that the facts will be considered worth recording.

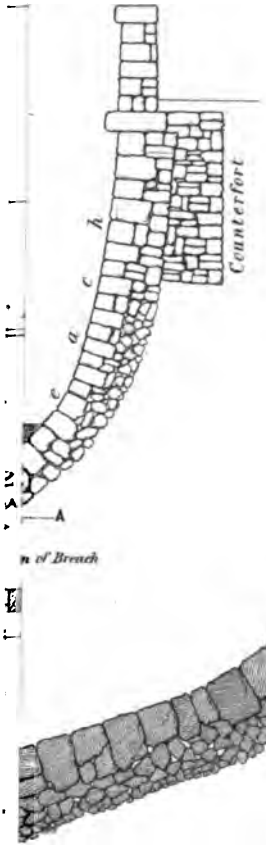
The Paper is illustrated by five diagrams, showing the section of the several sea walls described, and from which Plate 8 is compiled.

Major-General Pasley referred to an opinion expressed by him at a meeting of the Institution in 1842,* when he stated, that from "his observations of the action of the sea upon various parts of the

* *Vide* Minutes of Proceedings, 1842, vol. ii., p. 130.

Nº 3.

SECTION OF THE SEA WALL OF THE TURNPIKE ROAD BETWEEN NEWHAVEN AND TRINITY, SHEWING THE INJURY DONE TO THE PITCHING BY THE STORM OF THE 6TH DECEMBER, 1847.



Nº 4.

SECTION OF THE SEA WALL OF THE EDINBURGH, LEITH, AND GRANTON RAILWAY, NEAR TRINITY.
SHEWING THE AVERAGE EXTENT OF THE BREACHES MADE BY BY THE STORM OF THE 6TH DECEMBER 1847.

Nº 5.

SECTION OF THE SEA WALL OF THE EDINBURGH LEITH & GRANTON RAILWAY, NEAR GRANTON.

3, 4 & 5.

by setting back the parapet wall that distance from the face of the main wall, received the mass of the wave, and the high parapet finally prevented any considerable quantity of water from being projected over the wall. The principal injury had, therefore, been received by the slopes withinside the wall, and where no parapet was built, as within the estuary of the Exe, the waves had destroyed the slopes; but no other damage was done.

As it was always useful to give an account of even comparative failures, he would state, that with respect to that part of the work which was composed of dry-stone, it had been formed of blocks of a hard conglomerate, which were found in large quantities on the shore; the wall was about 25 feet high, by about 10 feet thick, and the blocks, when used, were only roughly shaped, so as to give them a kind of bed, that they might be laid together, without cement, like cyclopæan masonry. The whole had been destroyed, as General Pasley had described, while a wall built close beside it, of small ashlar masonry set in mortar, resisted perfectly the action of the same storm. Mr. Brunel ascribed the destruction of the dry-stone wall to the roughness of the surface, and the want of cement between the blocks, allowing the sea to enter and to dislocate and destroy the mass.

It was necessary to have pitching at the base of sea walls, in order to counteract the action of the receding waves, which was always powerful, where the water was only from 4 feet to 6 feet deep. On the southern coast he had constructed bulwarks in advance of the wall, to act as breakwaters, and as groynes, to collect the beach, in order to prevent the scour, which so frequently undermined and destroyed walls, whose foundations were even carried down to a considerable depth. A rock foundation would not always save them, for he had seen the surface completely rubbed away by the scour of the shingle, so as to render it necessary to underpin the wall, and to build an apron upon the rock, to prevent the recurrence of the same action.

Mr. GREEN said, that as a somewhat analogous instance, he might mention the Dymchurch wall, to which so much damage was done by the sea in the year 1803, that he was subsequently sent there, at the recommendation of the late Mr. Rennie, to carry out improvements in that extensive embankment, which protected from the sea a tract of not less than fifty thousand acres of marsh land, lying between the town of Hythe and the port of Rye. The wall, or embankment, was constructed entirely of earth; the face next the sea was defended by "Arming," which consisted of a facing of coppice wood, held down to the earthwork by oak stakes

and laths, in a very ingenious manner; but the front of the embankment had been laid at slopes of different inclinations, and in very irregular longitudinal directions. In some parts, the front slope formed nearly an angle of 45° with the horizon, or at an inclination of one horizontal to one perpendicular, varying in other parts between that slope and three horizontal to one perpendicular. The top of the embankment was in many parts at least 30 feet wide, and 20 feet above the level of extraordinary spring tides, and a great portion of it formed the public road from Hythe to Dymchurch and New Romney. It was customary to make large depôts of brush and coppice wood, for the occasional repairs of the embankment, on the top of the more elevated and the widest parts of it; but occasionally, the force of the sea was so great, at those parts having the steepest slopes, that the waves broke over the top, and carried the large stacks, of two hundred waggon loads of coppice wood, from the top of the embankment down into the marshes behind it.

In executing the repairs and the reconstruction with which he was entrusted, Mr. Green's first object, was to make the line of the face of the embankment, as nearly as possible, that of the general line of the shore, and to remove all sudden projections into the sea; and secondly, to bring the front slope of the embankment to an uniform inclination of seven horizontal to one perpendicular, the top of the embankment being only 6 feet higher than the level of extraordinary spring tides. The general inclination of the beach on the shore, from high water downwards, was, in that part of the shore, about eight horizontal to one perpendicular; but the face of the slope was defended by the coppice-wood arming, as before, as the expense of facing it with stone would have been beyond the means of the proprietors of the lands.

The plan pursued was found to answer extremely well, as, in the greatest storms, the surge of the sea never reached the top of the embankment.

This and other experience, convinced him of the propriety of so forming sea embankments, as to offer the least possible resistance to the direct force of the sea. He had since successfully constructed many other sea embankments, on the same principle, and had been fully confirmed in his opinion.

Mr. BORTHWICK said, that in the year 1833, Mr. Walker reported upon the state of the Dymchurch wall, and recommended a general amendment of its condition, which, he believed, was partly carried into effect, by the construction of a sloping pitched bank, with a vertical wall at the top. Mr. Elliott's paper, which was

read at the Institution in the session of 1847,* stated, that even that plan had been modified, and a general line had been adopted, with a pitched slope, at an average inclination of about eight horizontal to one perpendicular.

Mr. RENDEL knew the position where the walls described by Mr. Rankine were situated, as well as those on the coast of Devonshire, mentioned by General Pasley and Mr. Brunel. In his opinion there could be no comparison between the two cases. The former were situated in an estuary, sheltered by Inchkeith and the land of Fife, having, at the same time, a long shallow foreshore; whilst the latter were placed in exposed positions, with considerable depth of water, and heavy waves breaking upon them. A substantial wall, built of proper proportions, of good smooth-faced materials, with strong hydraulic lime, or cement, would stand well if it were nearly vertical, and a slope would also stand, if well packed with dry stones. The surface, however, must be such as to prevent the stones from offering such opposition to the waves, as to permit them to be loosened and torn up. In practice this was generally a question of relative cost, and in most cases a nearly vertical wall, well built in mortar, was found to be the cheapest.

The great difficulty was, to protect the toe of the wall, and to prevent it from being undermined; for even when the foundation was carried down to the rock, the beach, which had previously accumulated to a considerable depth, was not unfrequently carried away, and the surface of the rock was abraded to such an extent, by the travelling of the shingle, as to loosen the lower courses of the wall. In all such cases it was necessary, either to place a paved apron, or to construct groynes, for the purpose of collecting the shingle. The latter was perhaps the most effectual mode, if the litoral currents were well examined and taken advantage of, in settling the direction and position of the groynes. No conclusions, as to the best forms for breakwaters, could be deduced from examples of walls built like these, four-fifths up the shore. The cases were not in any degree similar, and it was necessary to be very careful not to assume any similarity of action, or of effect, between the long heavy deep waves, to which breakwaters were exposed, and the comparatively shallow and broken-up waves, to whose action the sea walls near Edinburgh were subjected.

Mr. SCOTT RUSSELL confirmed Mr. Rendel's view. The value of the arrangements shown in the sections, depended entirely upon the nature of the foreshore, the depth of the water, the length of

* *Vide* Minutes of Proceedings, 1847, vol. vi.

the reach for the sea to rise upon, and the direction of the exposure. It appeared to him, that the mass of masonry in the wall, (shown in Figs. 1 and 2, Plate 8) was so great, the depth of the water was so small, and it was comparatively so little exposed to the sea, that the form of the wall was of little importance, and the circumstance of its standing proved nothing. In the wall shown in Fig. 3, on the other hand, the perpendicular part was nothing more than a parapet, being protected by a sloping wall, up to the level of high water.

The thinness of the wall in Fig. 4, compared with that of Fig. 2, rendered any comparison uninstructive, as it was manifestly insufficient, and the foundation, which was only a loose rubble wall, was evidently inadequate; there was also a greater depth of water and more action of the waves, than in the case of the wall in Fig. 3.

The wall shown in Fig. 5 was precisely of the form to endanger the stability of the parapet; and it had given way, as might have been expected. It was similar to that on the Dublin and Kingstown Railway, of which a great part was thrown down by a storm, although it was built of large blocks of granite.

The general conclusions he was disposed to draw from the facts stated, and from similar instances which had come under his own observation, were, that a vertical wall, if it was composed of good masonry, united by strong hydraulic lime, or cement, not carried to a height exceeding 30 feet, and not exposed to the action of a heavy Atlantic swell; but protected by a long foreshore, or shallow water, would answer perfectly well, unless the foundation gave way. He might give as examples the quay walls of Liverpool, which were all built nearly vertical; they were also examples of excellent rubble work, which had resisted perfectly all the action to which they were subjected. In the case of exposure to a heavy breaching sea, or deep water, with large waves, it was necessary to begin to break the water as early as possible, and for this purpose a considerable slope would be found safer, and, eventually cheaper, especially with such materials as were, usually, most conveniently to be found for such purposes.

Mr. J. Thomson wished that Mr. Rendel had extended his observations, and had told them, for what positions he considered each kind of wall was best adapted; for although he thought, that the promulgation of any empirical rules must be prejudicial, yet there were conditions, under which certain forms of construction had been proved in practice to be bad, and it was very desirable to have such examples brought before the meetings.

Mr. Thomson thought, that the foundation, upon which the

wall, or the slope, was to be placed, was a principal consideration; if it was hard and sound, a vertical wall would, under ordinary circumstances, and with proper precautions, most probably stand well; but if it was soft and liable to be washed away, a slope, with a long pitched foreshore, must be preferable.

The situation, also, must be considered. If a sea defence was required to be built on the beach, near low-water mark, where the half tide would set upon it, with all its destructive force, a vertical wall was not desirable, however well the same wall might succeed, if it were placed out of the direct influence of the half tide.

With respect to the material, Mr. Thomson had found, that coursed rubble formed an excellent durable vertical sea wall, if laid in strong hydraulic mortar, or any cement, so that a smooth face could be given to the masonry, affording no salient points for the power of the water to be exerted upon; and even in slopes, it was more desirable to attend to having close joints, and smooth-faced stones, than to selecting those of large dimensions.

Major-General PASLEY thought, that the depth of the water against the foundation, should be considered, as, from the experience of the divers who operated, under his directions, upon the wreck of the Royal George, it appeared, that at certain depths, the water was comparatively still, when it was much agitated at the surface. It might be received as a rule, that the waves had little, or no force below the level of low water; and even at a depth of 6 feet below the tide level, he thought the force of the waves would be innocuous.

Mr. RENDEL, V.P., said, it was well known, that at a depth of about 12 feet below low water-mark, there was no injurious action of the waves, however deep the action of the tidal current might be.

Mr. BATEMAN agreed, that the specific gravity of materials employed under water should be considered; yet he thought, that their structure and qualities were of more importance. Some stones became softened, others readily disintegrated, others were chipped away, or their surfaces were worn away, by the travelling over them of sand and shingle, and others again appeared to be worn down by the action of the water alone. These were all to be avoided for submarine constructions.

He had seen some sea walls built of basaltic rock, which possessed great strength and solidity, standing well at an inclination of three to one; but the most remarkable example he recollected, was that of the Loch Foyle embankment, the face of which was pitched with a clay slate stone. By the action of the waves, small laminated portions were carried off, and were forced, like wedges, into the

interstices between the larger stones; the whole face by this means became so smooth, that not a crevice could be detected, and the waves rolled over the surface innocuously, having nothing to lay hold of in their passage. In fact, this material gave naturally, as perfect a surface as engineers endeavoured to obtain artificially, by laying large dressed blocks of stone, at a considerable expense.

Mr. MURRAY agreed with the preceding remarks, as to the abrasion of materials; it proceeded in some cases to such an extent, as to be a subject of serious consideration to the engineer. The faces of several glacis, or sea slopes, of four, or four-and-a-half to one, which he had constructed of hard limestone, had been so worn down and scooped out, by the action of the shingle when travelling over it, that constant repairs became necessary.

In the Harbour of Walker, there was a glacis faced with sandstone, full 3 feet in thickness. During the progress of the works, the small chippings of the stones formed a very sharp shingle, which being carried by the waves over the finished portion, wore it away, and injured it so extensively, that the sandstone pitching was obliged to be taken up and be replaced by whin-stone, and this, in spite of men being employed to clear the shingle from the surface of the glacis.

It was of the utmost importance to the duration of masonry, in such situations, that the action of the sand and shingle, under the influence of the tides and currents, should be carefully observed, as by the judicious erection of groynes, it was practicable to accumulate masses of sand, or shingle, which would act effectually as a protection for the works, or they might be made to deflect the travelling material into the deep water. This principle had been adopted with great success at the new harbour works at Sunderland, which he had mentioned on a previous occasion.*

The coasts of Holland exhibited many interesting examples of sea defences of various kinds. There the groynes were constructed of fascines, straw, and sand, and yet with these simple materials, which the Dutch Engineers had been compelled to use, from the absence, or great cost, of more durable substances, very effective structures were raised, which protected the coasts, and cost very little for repairs.†

Mr. RANKINE wished to explain, that he had not read Mr. Scott Russell's paper on Sea Walls,‡ before he had written the paper under

---

* *Vide* Minutes of Proceedings, 1847, vol. vi.
† Ibid, ibid, vol. vi.
‡ Ibid, ibid, vol. vi.

discussion; if he had done so, he should have referred to some parts, which were confirmed by his observations on the walls described. He begged it to be understood, that in giving this description, he had not pretended to lay down universal rules for the construction of breakwaters in deep water, from effects that had been produced upon walls founded on the beach.

He concurred in the principle, that an engineer ought to be guided by circumstances, in designing works; but he conceived that cases sometimes occurred, where the locality permitted the engineer to create such circumstances as he required; for instance, at Cherbourg, the want of a natural beach, on which to found the vertical face of the seaward side of the breakwater, was supplied by the flat summit of a stone embankment; it however remained to be shown by experience, whether that artificial foreshore was sufficiently extensive for its purpose.

Mr. Rankine thought Mr. Scott Russell somewhat underrated the power of the waves against the vertical wall at Trinity (Fig. 3). The fact, that a fishing-boat had been thrown over, and had been lodged upon the road, which was 8 feet above the high-water level of spring tides, showed, that the waves had acted on it throughout its whole height, and the exposure had been still further increased at the points, where the pitching had been carried away. He also pointed out, that the vertical wall (Fig. 3) was not exposed to a less depth of water, than the curved wall (Fig. 4), but rather to a greater depth, and an increased action of the waves.

Mr. C. H. Smith said it appeared to him, that in almost all engineering works, the specific gravity, or weight of the stone, was of the utmost importance, especially for low buildings which were occasionally under sea water, and where there was, perhaps, a rapid current, or in other situations, subject to the influence of powerful waves; such circumstances would require a heavy quality of stone to be used, because the weight of all bodies, when submerged, was reduced by that of the bulk of water displaced. The lightest stone he had ever found, in masses sufficiently large for building purposes, weighed only 103 lbs. per cubic foot, and if this was used in sea water, its weight would be reduced about 66 lbs., which was the weight of a cubic foot of sea water, and therefore it would be like building on land, with a material weighing but 37 lbs. per cubic foot.

The heaviest building stones that he had met with, were the dark grey varieties of sandstone, from the vicinity of Swansea, from Abercarne, from the Forest of Dean, and from Dundee; some of these were even heavier than granite, weighing upwards of 170 lbs. per cubic foot, and in his opinion, they would be quite as durable.

There was also a remarkably heavy stone found in some of the western islands of Scotland, particularly in the island of Tiree; it was composed of carbonate of lime, with a large quantity of hornblende in small nodules. He conceived, that such stones were peculiarly adapted for the building of docks, harbours, breakwaters, sea embankments, and indeed for all purposes, where the violent action of water was to be contended against. In situations where the stone was constantly, or alternately under sea water, sandstone was preferable to limestone, because it was not so likely to be acted upon by the *Saxicava rugosa*, the *Pholas*, or any other boring molluscæ, which frequently pierced calcareous stones to the depth of several inches, thus changing a smooth face to an extremely rough one, and consequently, by increasing the friction, rendering the stones more likely to be disturbed by the action of the waves.

The sea walls, or embankments in the neighbourhood of Leith, were constructed with Craigleith stone, which was a very good material for many purposes; but he believed that some of the rocks in the neighbourhood of Dundee, would furnish a preferable kind of stone for such works, because the Dundee stone weighed from 25 lbs. to 30 lbs. per cubic foot, more than the Craigleith stone, and it could be procured in blocks of much greater size at the same cost.

Mr. J. R. M'Clean said, that the Barrow and Piel sea embankments, of the Furness Railway, which were each about one mile in length, were somewhat peculiar in construction. The situation was generally well sheltered; but during the equinoctial gales, the banks were exposed to a heavy sea. The embankments were formed of sand, faced with a thickness of 12 inches of clay puddle, into which a thickness of about 4 inches of broken stone was beaten, so as to form a clay concrete bed to receive the pitching, or stone facing, which was 12 inches in depth. The portion of the embankment, above the level of the equinoctial tides, was faced on each side with sods, 6 inches in thickness, cut from the "salting." The grass, although on a slope of one to one on the inner side, was very strong and luxuriant, and the parapet thus formed, afforded a complete shelter for the railway. The cost of the stone facing, including the puddle concrete, was 1*s.* 6*d.* per superficial yard, and that of the sodding was 3*d.* per superficial yard. This form of embankment was, in his opinion, better adapted to the situation, and was constructed at less cost than an upright wall would have been.

He agreed with the statement made by Mr. Green, that the greater the slope of the face of the embankment, the less would be the disturbance to the foreshore; and he thought, that the necessity

for pitching, and putting down groynes to protect the foreshore, when an upright wall was built, proved, in a great degree, the correctness of this principle; more especially when the foreshore was composed of alluvial deposit, or other matter of a light description.

The Rev. the DEAN of WESTMINSTER directed the attention of Engineers, to the shape of the Cob Wall, which formed the extremity of the pier at Lyme Regis, Dorset. It was a nearly vertical wall, with a rounded end, built of Portland stone, and the stones were fastened together with oak dowels; it projected about a furlong into the sea, at a depth of 10 feet at low water, and was exposed to all the force of the Atlantic; but it was placed at such an angle to the run of the sea, that it appeared to divide the waves, deflecting one portion innocuously past, to expend itself, gradually, upon the beach, leaving still water within the port, and turning aside the other portion in such a manner, along the flank of the wall, that the body of water might interpose between the masonry and the succeeding wave, whose force was thus in a great degree expended before reaching the wall. Thus the greater the original wave, the greater was the resisting force of the mass of water, forming, as it were, a cushion for receiving the succeeding wave; and though the shingle beach had sometimes been driven in, during heavy gales, no injury had ever been done to the masonry of the wall.

There might be local, or engineering peculiarities in the construction of this pier, which had, perhaps, escaped the Reverend Dean; and he suggested, that it would form a good subject for a communication to the Institution.

Mr. WALKER agreed, in the impracticability of laying down abstract rules for the forms of construction of sea defences, suitable for all situations, when so much depended upon the local position, the force acting upon them, the direction of that force, and the quality and dimensions of the material of which the defences were constructed. The engineer must, in all cases, after considering the whole of the circumstances, combine his plan in accordance with scientific laws and practical experience, without attempting to fit an empirical formula to all cases, however dissimilar.

In many instances, nearly vertical walls cost less than long slopes, and this would be the case when the materials were expensive, from the distance they had to be conveyed. On the other hand, whenever the materials were close at hand, and so situated that an inexpensive kind of labour sufficed for placing them, long slopes would be least expensive.

Combinations of the two systems had frequently been proposed,

as in the original design for the Plymouth Breakwater, which was, that it should be composed of rough hewn blocks, thrown down upon a base of 70 yards wide, in a depth of 5 fathoms, rising to a width of 10 yards on the top, at 10 feet above the level of low water of spring-tides, up to which point the materials were supposed to form a slope of about three to one, and above it a nearly vertical wall of hewn stone was to have been built. The action of the sea upon this work, in carrying a large quantity of the stones from the seaward slope, entirely over the breakwater, and lodging them on the beach, showed that the inclination should be increased; accordingly, slopes of three to one for the land-side, and of five to one for the sea-side, were adopted, and had been since adhered to in the subsequent works, a long foreshore being at the same time formed.

At the western extremity, a buttress of hewn stone, at a less inclination than the other parts, had been constructed, under the directions of Mr. Walker; great pains were taken with the construction, the whole being bonded vertically from the bottom to the top, as well as horizontally, by dovetailing the stones and crossing the joints in both directions, in order to render it nearly a monolythic mass. The result of this was, that it had perfectly resisted all the action of the sea for the last six, or seven, years, when considerable injury had been received by the other ports.

At Dover, the part of the works now executing for the commencement of the Harbour of Refuge, was a wall with an inclination of only one-third of a foot horizontal to one foot vertical, in order to enable vessels to load and unload alongside it, and the main body of the work would be only at a small slope.

At the Channel Islands, where fine materials were close at hand, but labour was expensive, a long slope was intended to be adopted, up to the level of low water, and then a nearly vertical wall.

At Harwich, all the defences were laid at a long slope, having respect to the cost of materials and labour.

Great discrepancy of opinion existed, as to the rising of seas against nearly vertical walls. From lengthened observation, Mr. Walker was induced to believe, that in very deep water, where the direction of the wall coincided with that of the prevailing wind, the waves would not rise high upon it; but when the face was at a right angle to the sea, it would strike heavily and rise high.

This subject had been recently treated very ably by Sir Howard Douglas,* and his arguments in favour of long slopes were based

* *Vide* Reports of the Commissioners on Harbours of Refuge, 1846.

upon sound scientific reasoning, and practical examples, which entitled them to much respect.

Mr. Walker must repeat, that in practice, engineers must not expect to apply, successfully, any general rules in all cases; but must act from the dictates of their own reason, and the experience of former works under similar circumstances.

March 21, 1848.

JOSHUA FIELD, President, in the Chair.

No. 785.—"On Railway Junctions." By Arthur Beanlands, Assoc. Inst. C. E.

The present paper is intended to furnish an easy and correct method of setting out railway junctions.

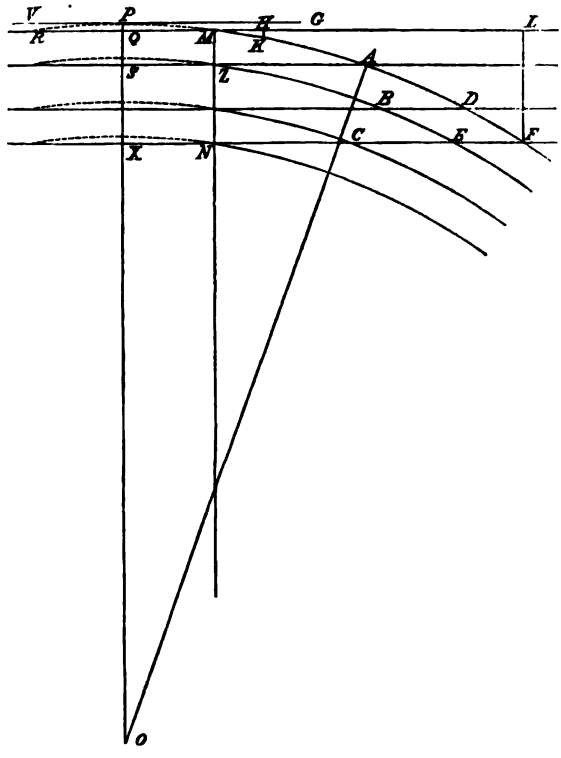
The Author is not aware whether this subject has ever yet been reduced to any formal rule, or whether the following, which he has found, practically, to be an easy and correct method of setting out junction curves, &c., is altogether new. It is not, however, improbable that it may have presented itself to other persons, in the same light in which he now endeavours to exhibit it; if therefore, it is not new, he must beg to be acquitted of any intention of appropriating that credit which may be equally due to other parties.

Every one versed in railway engineering, is familiar with the ordinary system employed, to enable carriages to travel from one line of railway to another, on the same level, by means of points and crossings, with their appendages. It is unnecessary to enter into any description of these, farther than to remark that the switch rail, or point, is usually between 12 feet and 15 feet in length, and is separated from the main rail, at the fixed extremity, by an interval of about 2 inches, so as to allow the flanches of the wheels to pass in the cavity.

It is supposed that the main line of railway is straight; that the junction line is an uniform curve, *i.e.*, a portion of one and the same circle, inclusive of the points themselves, when applied to the main rail; that the switch rail is 14 feet long, $2\frac{1}{2}$ inches broad at the fixed extremity, and 2 inches apart from the main rail; also that the lead of the junction, or distance from the points to the furthest crossing, is previously fixed upon. If then, the radius of the curve be 260 feet, or about four chains, which corresponds to a lead of 90 feet on the narrow gauge, the offset from the tangent in 14 feet, is $4\frac{1}{2}$ inches, which is the same as that made by the switch rail, as

above described, that is, 2 inches between the rails, and 2½ inches, the breadth of the rail itself. In this case, therefore, the curve may be set out from the main line by any of the ordinary methods, starting from it as a tangent at the points, the centre of course being in the line M N produced, perpendicular to the main line (Fig. 1).

Fig. 1.



But if the radius be larger than four chains, as it usually is, the offset which the curve makes from a tangent in 14 feet is less than 4½ inches, the offset which must be made by the points; in this case, therefore, the curve cannot be set out from the main line as a tangent, but must be made to start somewhat abruptly, making a finite angle with the main line. Hence, if the circle be completed, it will cross the main line at the extremity of the switch, a small arc M P R will be cut off by the straight line; and the curve will have a tangent parallel to the main line at the middle point P, of this small arc. The centre of the circle is evidently in the line P X O, at right angles to the main line; and before the curve can be set

out correctly by the ordinary methods, the chord M R, and the versed sine P Q of the arc M P R, must be ascertained in each particular case.

The question is simply this; the lead being fixed, there are given three points, namely, M and K, the two extremities of the switch rail when applied to the main rail, and F, the furthest crossing, and these three points will determine the circle.

Without entering into the details of the problem, which, however, is not very difficult, the result may be stated as follows:—

Let M H $= a$, length of switch,
H K $= b$, offset of switch,
M L $= \mathrm{A}$, lead of junction,
L F $= \mathrm{B}$, width of double line of railway,
M Q $= x$, Q O $= y$ } co-ordinates of centre of circle,
and P Q $= z$, versed sine of M P R.

$$\text{Then } x = \tfrac{1}{2}\,\frac{\mathrm{B}\,(a^2+b^2)-b\,(\mathrm{A}^2+\mathrm{B}^2)}{a\mathrm{B}-\mathrm{A}b}$$

$$y = \tfrac{1}{2}\,\frac{\mathrm{A}\,(a^2+b^2)-a\,(\mathrm{A}^2+\mathrm{B}^2)}{\mathrm{A}b-a\mathrm{B}}$$

These expressions determine the centre of the circle, and the radius $r = \sqrt{x^2+y^2}$, and $r-y=z$, the versed sine of the arc M P R.

From these data, the curve may be set out, in the usual way, by setting off the line P V, parallel to the main line at the distance P Q, and starting at P from P V, as a tangent, using the radius determined as above.

Before the rails of the junction can be laid, it will be necessary to ascertain the positions and the angles of the various crossings. These may be found, either by laying down the junction on paper, to a convenient scale, from the data previously found, or still more correctly by calculation.

Suppose the angle of the crossing A, and distance A Z, to be required, then

O S = Radius − P Q — width of gauge (centre to centre),
$\mathrm{A\,S} = \sqrt{(\text{Rad.})^2-\mathrm{O\,S}^2}$,
and A Z = A S − M Q;

also the angle of intersection at A = angle A O S, of which the trigonometrical tangent $= \dfrac{\mathrm{A\,S}}{\mathrm{S\,O}}$.

These angles are conveniently expressed in practice, in the same manner as the inclinations of gradients and slopes, by the proportion between the two sides of the triangle, as A S, and S O, of which

the former, the side opposite to the angle in question, is taken as unity. Thus if A S, be the fourth part of S O, the inclination of the crossing may be called one in four.

In order to facilitate the adoption of the foregoing method, a Table* is annexed to the Paper, in which the different values of the lead are taken, at intervals of 5 feet, from 100 feet to 300 feet, and the corresponding values of the radius, and of M P and P Q, and the distances and angles of the various crossings are given for each value of the lead. For any intermediate value of the lead, these quantities may be found with sufficient accuracy, by simply taking a proportional part of the difference in each column.

In this method, the lead of the junction has been assumed as a fixed quantity; but it is evident, that the table is equally applicable to the case in which the radius is previously determined, and the lead is made to depend upon it, the corresponding values of both being given.

The table, as before stated, is calculated for switches 14 feet long with 4½ inches offset; and if different dimensions be employed the quantities in the table should be a little different.

It is presumed, however, that within the ordinary limits, that is, one foot, or two feet, more or less, the error would be of no importance in practice. If the offset were increased, or diminished, in proportion to the length of the switch rail, the table would doubtless answer every purpose required.

The preceding method and the table, both assume, that the main line of railway is straight. Where both lines are curved, the question becomes somewhat more difficult; but the same principles may be employed in this case, that is, the radius of the main line being correctly ascertained, and either the lead, or the radius of the junction line being fixed, the other quantities may be found by calculation.

If the radius of the main line were large, in comparison with that of the junction line, it would not be difficult to make the necessary corrections, to render the table applicable, otherwise, it would be necessary to make an independent calculation to suit each particular case.

It would, however, extend the present paper to an unreasonable length, to enter fully into the details of such calculations, and the Author trusts, that enough has been said, to render intelligible the principles of this method.

The Paper is illustrated by a diagram appended to it, from which the wood-cut is taken.

* *Vide* pp. 208-9.

TABLE.

Lead, in Feet.	Radius, in Feet.	y	z	A		B	
				Distance from Points.	Angle, One in	Distance from Points.	Angle, One in
100	331	1·9	0·01	55·0	5·7	61·5	5·1
105	371	2·9	0·01	57·3	6·1	64·2	5·4
110	413	4·1	0·02	59·6	6·4	67·0	5·7
115	458	5·3	0·03	61·9	6·7	69·7	6·0
120	506	6·5	0·04	64·1	7·1	72·4	6·3
125	557	7·9	0·06	66·3	7·4	75·0	6·6
130	611	9·3	0·07	68·5	7·8	77·7	6·9
135	668	10·8	0·09	70·7	8·1	80·3	7·2
140	728	12·5	0·11	72·9	8·5	82·9	7·5
145	792	14·2	0·13	75·0	8·8	85·4	7·8
150	859	16·0	0·15	77·2	9·2	88·0	8·2
155	930	17·9	0·17	79·3	9·5	90·6	8·5
160	1004	19·9	0·20	81·3	9·9	93·1	8·8
165	1082	22·0	0·22	83·4	10·2	95·6	9·1
170	1165	24·2	0·25	85·5	10·6	98·1	9·4
175	1252	26·5	0·28	87·4	10·9	100·5	9·8
180	1343	29·0	0·31	89·4	11·3	103·0	10·1
185	1439	31·5	0·35	91·4	11·7	105·4	10·4
190	1538	34·2	0·38	93·3	12·0	107·8	10·8
195	1643	37·0	0·42	95·3	12·4	110·2	11·1
200	1753	39·9	0·46	97·2	12·7	112·5	11·4
205	1867	43·0	0·50	99·1	13·1	114·9	11·8
210	1988	46·2	0·54	100·9	13·5	117·2	12·1
215	2113	49·6	0·58	102·8	13·8	119·5	12·4
220	2246	53·1	0·63	104·6	14·2	121·8	12·8
225	2383	56·8	0·68	106·4	14·6	124·0	13·1
230	2527	60·7	0·73	108·2	14·9	126·3	13·5
235	2677	64·7	0·78	109·9	15·3	128·5	13·8
240	2834	68·9	0·84	111·6	15·7	130·6	14·1
245	2998	73·3	0·90	113·3	16·0	132·8	14·5
250	3171	77·9	0·96	115·0	16·4	135·0	14·8
255	3349	82·7	1·02	116·7	16·8	137·1	15·2
260	3538	87·7	1·09	118·3	17·1	139·2	15·5
265	3734	93·0	1·16	119·9	17·5	141·3	15·9
270	3939	98·5	1·23	121·5	17·9	143·3	16·2
275	4151	104·2	1·31	123·1	18·2	145·4	16·6
280	4374	110·2	1·39	124·6	18·6	147·4	16·9
285	4609	116·5	1·47	126·1	19·0	149·4	17·3
290	4852	123·0	1·56	127·7	19·3	151·4	17·6
295	5109	129·8	1·65	129·2	19·7	153·3	18·0
300	5374	137·0	1·75	130·6	20·1	155·2	18·3

This table is calculated for the narrow gauge of 4 feet 8½ inches, the width between the two lines of way being 6 feet clear; the switches are assumed as 14 feet in length, but the table will answer very well for 15 feet switches.

TABLE.

C		D		E		F	
Distance from Points.	Angle, One in	Distance from Points.	Angle, One in	Distance from Points.	Angle, One in	Distance from Points.	Angle, One in
54·1	5·6	83·2	3·8	82·7	3·7	100·0	3·1
56·4	6·0	87·3	4·0	86·7	4·0	105·0	3·3
58·8	6·3	91·2	4·2	90·7	4·2	110·0	3·5
61·0	6·7	95·2	4·4	94·7	4·4	115·0	3·7
63·3	7·0	99·2	4·6	98·6	4·7	120·0	3·9
65·6	7·4	103·1	4·9	102·6	4·9	125·0	4·1
67·8	7·7	107·0	5·2	106·6	5·1	130·0	4·3
70·0	8·1	111·0	5·4	110·5	5·4	135·0	4·5
72·2	8·4	114·9	5·6	114·5	5·6	140·0	4·7
74·4	8·8	118·8	5·9	118·4	5·9	145·0	4·9
76·5	9·1	122·7	6·1	122·3	6·1	150·0	5·1
78·7	9·5	126·6	6·4	126·2	6·3	155·0	5·3
80·8	9·8	130·5	6·6	130·1	6·6	160·0	5·5
82·8	10·2	134·4	6·8	134·0	6·8	165·0	5·7
84·9	10·5	138·3	7·1	137·9	7·1	170·0	5·9
86·9	10·9	142·1	7·4	141·8	7·3	175·0	6·1
88·9	11·3	146·0	7·6	145·6	7·6	180·0	6·3
90·9	11·6	149·8	7·9	149·5	7·9	185·0	6·6
92·9	12·0	153·6	8·1	153·3	8·1	190·0	6·8
94·8	12·3	157 4	8·4	157·1	8·4	195·0	7·0
96·8	12·7	161·2	8·7	161 0	8·7	200·0	7·2
98 7	13·1	165·0	8·9	164·8	8·9	205·0	7·5
100·5	13·4	168·8	9·2	168·5	9·2	210·0	7·7
102·4	13·8	172·6	9·5	172·3	9·4	215·0	7·9
104·2	14·2	176·4	9·7	176·1	9·7	220·0	8·2
106·0	14·5	180·1	10·0	179·8	10·0	225·0	8·4
107·8	14·9	183·8	10·3	183·6	10·3	230·0	8·6
109·5	15·3	187·5	10·6	187·3	10·6	235·0	8·9
111·3	15·6	191·2	10·9	191·0	10·8	240·0	9·1
113·0	16·0	194·9	11·1	194·7	11·1	245·0	9·4
114·7	16·4	198·6	11·4	198·4	11·4	250·0	9·6
116·3	16·7	202·3	11·7	202·1	11·7	255 0	9·9
118·0	17·1	206·0	12·0	205·8	12·0	260·0	10·1
119·6	17·5	209·6	12·3	209·4	12·3	265·0	10·4
121·2	17·9	213·3	12·6	213·1	12·6	270·0	10·6
122·8	18·2	216·9	12·9	216·7	12·9	275·0	10·9
124·3	18·6	220·5	13·2	220·3	13·2	280·0	11·1
125·9	18·9	224·1	13·5	223·9	13·5	285·0	11·4
127·4	19·3	227·7	13·8	227·5	13·8	290·0	11·7
128·9	19·7	231·3	14·1	231·1	14·1	295·0	12·0
130·3	20·0	234·8	14·4	234·6	14·4	300·0	12·3

In the course of the discussion which ensued upon this method, as compared to the ordinary system of setting out junctions, by a comparatively empirical rule, well understood and practised by the plate-layers on railways, Mr. Wild's switch was alluded to and exhibited. In this switch all notching and inequality in the bearing surfaces of the fixed rails were shown to be avoided, by the ends of the tongues being housed under such surfaces, instead of being notched into them: the tongues being consequently at their points, and for some distance beyond them, lower than the fixed rails, exercised where they were weakest merely a lateral action against the wheels without bearing any of the weight of the passing train.

Several engineers, who had employed these switches extensively, expressed themselves relative to them in commendatory terms, and stated that they were not only manufactured in a superior manner, but that their action was perfect, and that they tended greatly to the prevention of accidents in railway travelling.

March 28, 1848.

JOSHUA FIELD, President, in the Chair.

No. 773.—"The Engineering of the Rhine," including a Translation of M. Van den Bergh's Paper, "On the Improvements of the Moselle."* By George Briant Wheeler Jackson, Assoc. Inst. C.E.

THE main object of the present Paper, in describing the works on the Rhine, considered in connection with a previous Paper on the North Holland Canal, read during the Session of 1847,† is to give some further particulars of the use of fascine work, or arming, and the situations in which it is most advantageously applied.‡

In addition to the information obtained by the Author's personal inspection, he has thought it desirable to introduce extracts from the following writers:—Messrs. Beaudemoulin, Van den Bergh, Desfontaines, Dr. Hibbert, Baron Krayenhoff, and Messrs. Ockhart, and Wiebeking.

The Rhine takes its rise from the Badus, one of the Swiss mountains in the Canton of the Grisons, and during its passage through the rocky defiles of that country, receives the waters of many valleys, until it reaches the Austrian frontier, where it is joined by the Ill, and both flow northwards into the Lake of Constance, which is about 42 miles long and 8 miles wide. From the town of Chur in Switzerland, where the stream is about 200 feet wide, it becomes navigable, but only for small craft, and even then not without danger.

The bed of the river, at its commencement, is composed of granite, gneiss, and micaceous schist; thence to Chur, of grauwacke; and from Chur to the Lake of Constance, of the oolite Jura group. This latter stratification forms a very considerable tract, extending from Vienna on the east, and running through Innspruck, and a portion of the Bernese Alps, to the Rhone, and the Gulf of Genoa. On the Lake of Constance the shipping is equal in size to that on

* The discussion upon this Paper extended over portions of three evenings, but an abstract of the whole is given consecutively. Some discrepancies in the measurements exist in the original MS., which, in consequence of the decease of the Author, it has not been practicable to correct.

† *Vide* Minutes of Proceedings Inst. C.E., 1847, vol. vi., page 81.

‡ In the original manuscript, the geology of the Rhine, together with the historical changes of its bed, especially in Holland, are fully described; but these do not offer sufficient interest to warrant their being here printed at length.

the Upper and Middle Rhine, and barges can proceed without much difficulty, to the Falls of Schaffhausen, which are from 60 feet to 70 feet in height. The geological character of this portion of country is of the tertiary order. At Schaffhausen there formerly existed a famous bridge, which was destroyed by the French in 1799; it was 376 feet 9 inches long and 15 feet wide in the clear. From this place westwards, the river widens to 600 feet and 700 feet, receiving the Aar, and thus containing four-fifths of the waters of Switzerland; it then forms the boundary between Switzerland and the Grand Duchy of Baden, as far as Bâle, and northwards between the latter and France, nearly to Carlsruhe. At Zurzach, Lauffenburg and Rheinfelden, the bed is very rocky and full of breakers; the Jura group and the red sandstone formation again appearing on its banks above Bâle, from which place to the Taunus Mountains, only sand and gravel are found. A traveller from Bâle in a northerly direction beyond Strasbourg, would have on the right the mountains of the Black Forest, consisting more, or less, of granite and the old red sandstone series, whilst on the left would be the Vosges, of similar structure, as far as the Taunus, and then the limestone hills, near Mayence. Before arriving at this town, a considerable number of shoals of sand and gravel are met with, which, as they are continually shifting and forming fresh and exceedingly sharp curves in the stream, cause great inconvenience to the navigation. From Bâle to Mayence, the width of the river increases from 750 feet to 1,400 feet; whilst the depth from Bâle to Strasbourg varies from 3 feet to 10 feet, and thence to Mayence from 5 feet to 18 feet and even 24 feet. At Mannheim between the two last-named places, the steamers and heavier craft commence their passages; the Rhine there receives the waters of the Neckar, and afterwards at Mayence, those of the Main. From Carlsruhe to Mannheim and Bingen, the Rhine passes successively through the States of Baden, Bavaria, Hesse Darmstadt, and Nassau. The most beautiful portion of the Rhenish scenery extends from Mayence to Cologne; it is also the most interesting, as it includes a vast tract of volcanic groups which have long occupied the attention of the learned geologists of Germany. At Bingen the Rhine is joined by the Nahe, and the channel, (very considerably contracted and passing between the high perpendicular rocks of the Hundsrück, of the grauwacke series of the silurian system, which dip very sharply), winds its course over a rapid succession of breakers, past St. Goar to Coblenz, and thence to the so-called basin of Neuwied. Until of late years, the rapids of Bingen rendered the only navigable channel exceedingly dangerous

and almost impassable, it being scarcely more than 13 feet to 20 feet wide, with a velocity of 11 feet per second. It has since been so far improved by blasting, under the superintendence of M. Van den Bergh, as to make it navigable for considerable craft under the management of experienced pilots; but the rushing of the waters over sunken rocks may still be heard, at certain periods, for some distance. At Coblenz, first the Lahn and then the Moselle bring their additional streams, the latter being equal to about one-third of the Rhine. Northwards, passing through Rhenish Prussia, below Coblenz to Andernach, the Rhine is 1,400 feet wide and from 8 feet to 20 feet deep; the shores consisting more, or less of pumice-stone, lava, and other volcanic formations. It then narrows, and enters the gorge at Andernach, passing through a range of grauwacke, basaltic and sandstone hills with porphyry, more, or less of the silurian system, with a general depth of water of from 10 feet to 20 feet, until it reaches the Seven Mountains at Bonn near Cologne, where it opens upon a country produced by deposits of gravel and sand, brought down from the high lands of Germany, averaging there 1,300 feet in width and 13 feet in depth. During this latter course it receives the Aar and the Sieg. From Cologne it flows past Düsseldorf, at which place it is from 50 feet to 70 feet deep, having previously taken up the Wipper, and being subsequently joined by the Ruhr, both of which streams are navigable. It then enters the Dutch frontier near Emmerich, below Wesel, forming above Nymegen and Arnhem three distinct arms,—the Waal, the Yssel, and the Old Rhine; the Waal joining with the Meuse and running into the North Sea at Helvoetsluis,—the Yssel flowing into the Zuider Sea,—and the Old Rhine again separating at Wÿk, into the Leck and the Old Rhine, the former passing into the North Sea, by way of Rotterdam, at the Briel, the latter at Katwÿk, by way of Leiden. The average depth through Holland may be stated at from 5 feet to 10 feet; the width at Lobeth being from 1,400 feet to 2,300 feet.

The entire extent of country watered by this river is generally divided into the Upper, the Middle, and the Lower Rhine; the first extending from its rise in Switzerland to Mayence, a distance of 509½ English miles, with a fall of 7,004 feet, the second from Mayence to Cologne, 116¾ English miles, with a fall of 113 feet, and the third from thence to the sea, a further distance of 223½ English miles, with a fall of 123 feet, making a total run of 849½ miles. It receives the drainage of 72,859 square English miles, the greatest area drained by any of the rivers of Europe, excepting those of Russia and the Danube.

Throughout the whole extent of the Rhine below Mayence, only two classes of bridges are allowed, the common fixed boat-bridge and the flying-bridge, the latter of which has been improved, by additional guiding chains attached to the first boat and four sheaths, the two front, or hinder, being dropped into the stream according to the shore to be reached; the landing-places being generally on the shores and rarely advanced into the stream. At Mayence and Cologne, near the bridges, there are floating corn-mills in a line across the stream, leaving three passages free for the navigation.

The following Tables have been carefully compiled from the best authorities:—

TABLE I.—Containing the Levels, Widths, Slopes, and Depths of the Rhine, from its Source to Holland.

Localities.	Levels above the Sea.	Widths.	Slopes.	Depths.
	Feet.	Feet.		Feet.
At the commencement in Switzerland . .	7,440	..	1 in 5	
Reichenau . . .	3,880	230	to 1 in 47	
Lake of Constance.	1,316	300	to 1 in 108	
Bâle (Bridge) . .	820	750	1 in 1,341	3 to 10
Kehl (Bridge) . .	451	1,100	1 in 1,660	
The Lauter . . .	348	1,100		3 to 12
Mannheim (Bridge)	302	1,200	1 in 4,600	5 to 18
	Levels above A. P. *		1 in 6,000	
Mayence . . .	240·5	1,300 to 1,400		5 to 24 & 30
			1 in 5,280	
Bingen	229·3	1,160	1 in 3,000	6 to 20
Coblenz . . .	198·7		1 in 6,631	
			1 in 4,600	
Bonn	151·4	1,240		8 to 24 & 29
			1 in 3,700	
Cologne . . .	126·6	1,300		8 to 23
			1 in 4,400	
Düsseldorf† . .	95·7	1,200 to 1,300		7 to 70
			1 in 5,710	
Wesel	57·6	1,580		25 to 29
			1 in 7,300	
Emmerich . . .	42·33	1,400 to 2,150		9 to 15

* Amsterdam Peil, or the Dutch Benchmark.

† The dykes are from 110 feet to 119 feet above A. P.

TABLE II.—Containing the Velocities and Quantities of Water in the Rhine, from its Source to Holland.

Localities.	Velocities in Feet per Second.	Average Depth in Feet.	Quantities in Cubic Feet per Second.
Bâle to Lauterburg	At low water . . . 8·6 to 3·1	..	11,673 above Vieux Brisach. 15,965 at the Bavarian frontier.
	At average water . . 9·3 to 4·9	..	40,385 above Vieux Brisach. 37,972 at the Bavarian frontier.
	At high water . . . 13·8 to 9·3	..	158,757 at Bâle. 172,010 ,,
Lauterburg	.. ..	..	159,650 199,477
Below the village of Erfelden	On the surface . . . 3·6 to 3·1 At the depth of 4 feet . 3·7 to 4·1 ,, 6 ,, . 3·6 to 3·7 ,, 20 ,, . 3·5 to 3·0	8	37,883 with 9 feet of water.
Mouth of the Aar	At 5 ft. 11 in. Cologne level 6 inches below the surface . . 5·1	13 to 19	
Linz	,, ,, 5·4		
Honneff	,, ,, 4·7	..	39,168 with 9 feet of water.
Ober Cassel, near Bonn	,, ,, 5·5		
Nieder Cassel, near Brühl	,, ,, 3·4	$8\frac{1}{2}$ to 10	
Cologne	,, ,, 5·2		
Düsseldorf	At 3 feet, Düsseldorf level 6 inches below the surface . 5·6	$7\frac{1}{2}$	
Bloesheim Ferry below Herdingen	,, ,, 4·4	$7\frac{3}{4}$	

TABLE III.—Containing the Levels, Widths, Slopes, and Depths of the Rhine, through Holland to the Sea, including the Levels of the Dykes.

	Localities.	Levels above A. P. in Feet.	Widths in Feet with 5 Feet 8 Inches of Water.	Slopes.	Depth in Feet.	Levels of Dykes above A. P. in Feet.
Along the Waal.	Emmerich .	42·33	1,413		7·8	R 58·6 L 57·9
				1 in 8,500		
	Nymegen . .	29·74	1,315		9·5	R 46·2 L 47·4
				1 in 7,080		
	Ochten . .	20·21	..		..	R 35·8 L 36·0
				1 in 10,843		
	Tiel . . .	17·37	1,920		..	R 32·5 L 32·3
				1 in 7,011		
	Bommel (reach of tide) . .	8·84	1,665		..	R 26·1 L 25·1
				1 in 15,105		
	Woudrichem .	5·11	..	1 in 11,106	3·1	R 17·7
		3·71		1 in 67,000		L 18·5
	Gorcum . .	4·78	..	1 in 32,104	..	R 16·4
		3·30		1 in 93,000		L 16·8
	Hardinxvelt .	4·46	..	1 in 11,100	..	R 15 8
		2·28		1 in 24,003		
	Dordrecht. .	+ 3·93	679 to 1,560	1 in 15,103	..	R 11·8
		− 1·65		1 in 54,859		L 13·0
	Krimpen . .	+ 3·42	..	1 in 28,800	..	R 13·3
		− 0·65				L 13·0
Along the Pannerden Canal and the Leck.	Emmerich .	42·33	..		..	R 58·6 L 57·9
				1 in 8,504		
	Pannerden .	34·72	..		8·10	R 51·6 L 51·6
				1 in 7,843		
	Arnhem . .	29·09	603 to 605		7·3	R 44·5 L 44·8
				1 in 10,951		
	Wÿk . . .	14·92	..		..	R 28·7 L 28·2
				1 in 11,106		
	Kuilenburg .	11·3 to 13	..		..	R 24·6 L 23·6
				1 in 10,429		
	Vianen (reach of tide) . .	7·7	..		7·4	R 21·0 L 20·0
				1 in 19,157		
	Schoonhoven .	4·2	..	1 in 12,390	..	R 17·4
		2·4		1 in 64,237		L 17·1
	Krimpen . .	+ 3·4	..	1 in 18,000	..	R 13·3
		− 0·6		1 in 135,000		L 13·0
	Rotterdam .	+ 2·8	1,500	1 in 35,628	..	R 11·7
		− 1·6				L 11·4
	Briel . . .	+ 2·8	5,190	1 in 162,200	12 at L.W.	R 13·2
		− 2·1				L 14·3

TABLE III.—Containing the Levels, Widths, Slopes, &c., of the Rhine—*continued.*

	Localities.	Levels above A.P. in Feet.	Widths in Feet with 5 Feet 8 Inches of Water.	Slopes.	Depth in Feet.	Levels of Dykes above A.P. in Feet.
Along the Meuse.	Grave . . .	17·57	..	1 in 20,900	6·0	R 36·8 L 37·1
	Batenburg . .	14·90	..	1 in 40,000	..	R 33·4
	Fort St. Andries	12·22	..	1 in 15,200	..	R 26·8 L 26·5
	Krevekeur .	8·78	..	1 in 13,430	..	R 23·7 L 23·9
	Heusden . .	6·25	..	1 in 41,000 to a much flatter	..	R 21·5 L 22·2
	Helvoetsluis .	+ 3·0 to 6·0 − 2·8	8,872		25 to 37 at L. W.	
Along the Yssel.	Arnhem . .	29·09	..		..	R 44·56 L 44·8
	Westervoort .	30·73	..	1 in 8,000	6·8	R 45·8 L 44·3
	Doesburg . .	21·72	318 to 327	1 in 9,800	4·6 to 5	R 33·4
	Zutphen . .	12·33	..	1 in 11,000	4·5 to 5·2	R 27·4 L 26·9
	Deventer . .	8·21	..		6·2	R 26·6 L 22·8
	Kampen (reach of tide) . .	0·94 0·68	..	1 in 22,000 1 in 40,000	2·9 2·6	R 9·1 L 9·2
	Zuider Sea .	+ 0·10 − 0·39	..		4·0 3·5	L 6·0

+ indicates above A.P.; − indicates below A.P.

At Utrecht, the level above A.P. is 1·1 foot.

At Amsterdam, the level is = A.P., varying to 1·53 foot below A.P.

At Katwÿk, the cill of the sluice is 6·11 feet below A.P.; the highest flood is 11·21 feet above A.P.; the ground is 11·37 feet above A.P.

TABLE IV.—Containing the Velocities and Quantities of Water in the Rhine, through Holland to the Sea.

Localities.	Average Depth in Feet.	Mean Velocities in Feet per Second at 6 Feet Arnhem Level.*	Quantities at 6 Feet Arnhem Level. — Cubic Ft. per Second.	Quantities at 9 Feet Arnhem Level. — Cubic Ft. per Second.
At the Spÿk Passage . .	13·58	3 56	67,558	111,982
Byland Canal . .	16·3	3·53	66,499	
Pannerden Canal .	8·6	3·73	20,224	36,642
Yssel	7·7	2·86		
On the Yssel.	8·1	3·7 to 2·3	5,203	
Waal.	11·0	† 3·4 to 2·0	47,060	75,320
Merwede, above Oude Wiel . .	21·0	† 1·59	60,667	
Merwede, below Oude Wiel . .	7·3	† 1·85	16,335·8	
„ including creeks . . .			44,269·5	
			60,605	
At Helsloot	8 1	† 2·43		

From these Tables it will be perceived, that, at the division of the Rhine, the Waal receives two-thirds, and the Pannerden Canal one-third, of the whole quantity of water brought down. Of the one-third which passes along the Pannerden Canal, the Yssel receives one-sixth, or one-eighteenth of the whole, and the Leck five-sixths or five-eighteenths of the whole. Brunning, the Dutch Engineer, setting the level at from 3 feet to 4 feet, Arnhem level, and the total quantity at 100, puts for the Waal, 68·3; and for the Pannerden Canal, 30·7; and of the latter, for the Yssel, 5·5; for the Leck, 25·2.

If at 8 feet of level, the average quantity of water passing through the Spÿk passage is taken at about 74,655 cubic feet per second, or 2,354,320 millions of cubic feet per year, and the surface of drainage up to this place at 71,000 square miles, the result would be, taking the area at 1,979,356 millions of square feet, an annual delivery of about 14 inches to 15 inches of water per square foot. Starting from the point of separation of the Rhine and the Waal, and measuring equal distances along each, it will be perceived, that at Nymegen, the Waal is higher than the point at the same distance along the canal and the Leck, but after that point is past, the Waal is the lowest in

* In 1792, at a level of water of 9 feet, Arnhem level, the velocity of water, per second, in the undivided Rhine amounted to 4·15 feet; in the Waal to 3·85 feet; and in the Pannerden Canal to 4·6 feet.

† Most probably taken by Krayenhoff at the turn of tide.

levels throughout; and that at Dordrecht the difference amounts to 3½ feet.

The following particulars have been collected in reference to the depths at high water, and at floods:—

Year.	Meuse, at Grave.	Rhine, at Cologne.	Rhine, at Emmerich.	At the Pannerden Canal.	Waal, at Nymegen.	Rhine, at Arnhem.	Merwede, at Gorcum.	Leck, at Vianen.	Yssel, at Doesburg.
1784 . .	At Düsseldorf, with ice, 32 feet 8 inches.								
1795, Feb.	..	..	21·5	..	21·4	..	9·8	16·9	..
1799, Feb.	21·5	25·5	22·11	..	25·0	20·0	13·5	19·6	..
1809, Jan.	19·3	27·5	22·10	25·1	26·0	20·0	15·3	14·8	19·3
1819 . .	At Bâle, 3 feet above the highest former floods.								
1845 . .	At Düsseldorf, without ice, 27·4 feet.								
1802 and 1808 . .	20 feet above low water at Strasbourg, and 15 feet above low water at Mayence.								

The lowest waters have been ascertained to be:—

Year.	Depth at Cologne.	Depth at Emmerich.	Depth at Pannerden Canal.	Depth at Nymegen.	Depth at Arnhem.	Depth at Gorcum.	Depth at Vianen.	Depth at Doesburg.
1800. . . .	6·10	4·0	5·5	6·5	3·9	1·8	4·8	1·4
1814 (24 Nov.).	..	..	..	5·4	Old Rhine, only 11 inches.			
1832 (2 Nov.) .	At Düsseldorf, only 2·7 feet.							
Average waters 1782 to 1810 .	9·1	7·10	9·1	9·8	7·5	3·2	7·8	5·1

The Emmerich level is 3 feet 3 inches above the Arnhem level, the Arnhem level is 1 foot 1 inch above the Nymegen level, and the Nymegen level is 8½ inches above the Grave level, when the Waal and the Meuse are at the same height.

It is mean water level on the Rhine when it is 4½ feet at the Arnhem level.

" " Yssel when it is 8½ feet at the Zutphen and Doesburg levels.

" " Waal when it is 5½ feet at the Nymegen, Tiel, and Bommel levels.

" " Meuse when it is 4½ feet at the Batenburg and Hedel levels.

The effects upon the level of the Rhine produced by the streams, may be seen by the following instances:—

1st May, 1789. The level of the Rhine at Cologne was 15·96 feet.
2nd " " was raised by the Sieg, to. 18 00 "
3rd " " at Cologne was . . 9·52 "
4th " " was raised by the Sieg, to. 15·45 "
17th Dec. 1790. " at Cologne was . . 11·10 "
20th " " was raised by the Sieg and the Moselle, to . . 19·94 "

The following is a list of the places where the principal breaches in the dykes have occurred, with the dates, since 1421 :—

1421. Above Oude Wiel.

1565. In the Dief Dŷk on the Merwede, in three places.

1570. In the Diemendam, in thirteen places, by which a great surface of country became inundated, and one hundred thousand people were swept away; the repairs costing 4,000,000 guilders.

1625. On the Leck, when the water covered the surrounding country of Utrecht.

1653. Along the Rhine and the Waal.

1658. At Hardinxvelt.

1663 to 1686. In various places, owing to storms, floods, &c., by which a large portion of country was laid under water.

1711. In the Botter Dŷk, which occasioned the Rhine to discharge a greater quantity of water into the Waal.

1744. Between the Leck and the Waal, the water rising to 17 feet above A.P. at Vreeswŷk. (When the water level is 11 feet 7 inches above A.P., notice is given by sounding the tocsin.)

1753 to 1757. In several places on the Upper Rhine, the Waal, the Meuse, and the Yssel.

1795 to 1809. Along the Yssel and the Rhine, in consequence of severe ice-floods.

1799. In twenty-three places, inundating a surface of country of 1,300 square miles.

1820. On the Waal.

Since 1700, the dykes have been raised to a somewhat uniform level; near Düsseldorf, to 15 feet and 25 feet above ordinary water; at Emmerich, Arnhem, and Nymegen, to 18 feet, and thence to Rotterdam, to 12 feet above the ordinary water level; nevertheless, the low lands are regularly flooded at very high water to counterbalance the exterior pressure on the dykes, it being borne in mind, that the waters of the sea, the Yssel, and the Leck are higher than the polder lands. Above Düsseldorf, on any very sudden rise of the Rhine from the melting of ice, or snow, the river is apt to overflow its banks at Mannheim, Mayence, Coblenz, Neuwied, and Cologne, and this may be attributed to the abrupt rocky banks, the sharp curves, or elbows, and the narrow channels generally existing below these localities. It is, however, very fortunate, that the waters from the Vosges, the Black Forest, and the Moselle, arriving twenty-four hours before those from Switzerland, and the latter only three days after any extraordinary increase of temperature during spring, enable the authorities of each State to acquaint those of the lower ones by preconcerted signals, when the ice and snow are beginning to move.

The result of floods and inundations along the Rhine has proved, that the lands in the vicinity of its banks, are generally those most rapidly raised. In the year 1797, the thickness of material deposited on the lands near Darmstadt, was calculated at 3 inches. Mr. Shaw estimates the Nile deposit as equal to $\frac{1}{110}$th of the bulk of water overflooding the land, but Mr. Perry puts it at $\frac{1}{300}$th. German authorities fix that of the Elbe at $\frac{1}{311}$th, and of the Rhine at $\frac{1}{770}$th during floods. On the 31st of January, 1799, several experiments were made by Wiebeking, after the breaking up of the ice, and the Rhine was then found to hold in suspension $\frac{8}{1000}$ths of solid matter. In Holland, Tetens estimates the amount of deposit at $\frac{1}{300}$th and $\frac{1}{600}$th, Bolstra at $\frac{1}{1000}$th, and according to Wiebeking, this mud contains $85\frac{5}{10}$ grains of earthy particles, with $3\frac{5}{10}$ grains of calcareous matter. Some of the gravel brought down by the smaller streams, such as the Moselle and the Aar, is so ponderous as to contain pebble stones weighing 25 lbs. each, which roll on and get broken up by degrees, so that below Arnhem and Nymegen, they appear as coarse sand, whilst nearer the sea, the whole becomes extremely fine sand. To show the cohesion of particles of water with so much matter in suspension, it may be further stated, that the divisions of the Moselle and the Rhine can be traced for nearly two miles down the stream.

On the Construction of the present Works on the Rhine.

The works lately undertaken on the Rhine consist of cuts for straightening the course, of dams, of weirs, of division arms, of spurs, of shore works, and of rock blasting. The whole extent is divided, for the sake of convenience, into three districts:—the French district from Bâle to Lauterburg;—the Prussian district from Lauterburg to Emmerich;—and the Dutch district from Emmerich to the sea. As to the Swiss portion, it will only be necessary to state, that on account of its rocky bed, the usual methods of damming up by rectangular weirs, and of planting with wood when practicable, are resorted to, for the purpose of lessening the velocity of the stream as much as possible.

The French district extends from Bâle to Lauterburg, and forms a gravelly and sandy portion of country. The works for the improvement of the Rhine here were carried out, more, or less under the superintendence of M. Desfontaines, who, in speaking of the Rhine, says, that it offers very great difficulties for the Engineer to control, on account of the vast volume of water, the great velocity, the tendency of the bed to move and shift, and the depth

occasionally increasing, in twenty-four hours, to the extent of 30 feet, and even 45 feet. He adds that, to judge by artesian wells sunk in Strasbourg, the gravel continues 150 feet below the summer low-water level. In speaking of curves and elbows M. Desfontaines observes, that, on rivers with sand and gravel and subject to sudden floods, the stream having a radius of half a mile does not wear the beds, or shores, and where these latter are artificially preserved, though of a height of 20 feet, they are not injured, if possessing a radius of a quarter of a mile. M. Möglingen, the Engineer of Düsseldorf, takes two to two-and-a-half times the width of the stream for the diameter of the sharpest curve, which very nearly agrees with the opinion of M. Desfontaines, as the shore of the Rhine at Düsseldorf is artificially preserved.

Above Strasbourg are the cuts, or straightening channels, such as Lobensteinswerth and others, originally cut 2 yards deep and from 8 yards to 20 yards wide, which appear to have succeeded very well in deepening themselves, solely by the force of the stream. The main works of this district, however, are found near Strasbourg. They consist of dams for closing up arms of the river, and are principally constructed with fascine bundles and solid basket-work, as at Raukopf, Schiffbruckgrund Giesen, Laemmerich Giesen, Blanelsand, Hellwasser, Steingrund Giesen, &c. These dams are generally placed perpendicular to the banks, and at 200 yards to 250 yards from the main up-stream opening, with one, or two additional after-banks, according to the force of the water, for the purpose of removing the action of the overflow, as much as possible, from the main dam. The greatest difficulty exists in stopping the beds from being worked out and the dams from sinking. Before 1810, only ordinary fascine bundles and hurdling were used; but, since then, baskets filled with gravel and broken stone have been substituted, with good effect. In describing these dams it will suffice to notice only one, that at Raukopf.

The dam at Raukopf is below Strasbourg; it is 335½ yards long at the ordinary depth of water, which is 14½ feet, having a general velocity of 6 feet 6 inches per second. It was commenced in 1821 and finished in 1822, and as the channel ran from one shore obliquely to the other, the direction of the dam was laid from each shore, (in unequal lengths,) so as to form a salient angle against the stream. Excavations were accordingly made in the shore banks, and then two counterforts were worked in, constructed with ordinary hurdling on bundles, picketed down, the one on the left extending 48 feet 9 inches into the water, because the ground was rotten, whilst that on the right extended 113 feet 9 inches. At the same time sixteen

anchor piles were driven in, at distances of about 65 feet at right angles to the shores, and about 65 feet up-stream from the salient angle of the dam. Each pile-head was strongly corded, and held fast by capstans on the land. The dam itself consisted, first, of a general base, 81 feet 3 inches behind the intended front slope, 97 feet 6 inches broad, and 27 feet 6 inches high, for the purpose of preserving the bed from being deepened. This base was constructed with conical baskets filled with gravel, each basket being 13 feet long and 2 feet 6 inches in diameter; three of these baskets were secured together by transverse poles and cordage, and were thrown down through openings in boats built for the purpose and moored over the spots. One thousand six hundred and fourteen triple baskets were thus sunk, and one hundred and forty-three single ones were added to fill up vacancies, together with 61,000 cubic yards of sand and gravel; and the foot and head of the base were further secured with 700 cubic mètres, or 24,717 cubic feet of stone blocks. The fall of water which this work had to sustain amounted to 4·87 feet and 6 feet 6 inches; and this it resisted without any damage. In front of this base up-stream, one hundred and ninety-nine piles of fir were driven 16 feet 3 inches into the bed of the river, which piles were 0·97 foot by 1·04 foot, and from 35 feet 9 inches to 39 feet long. They consisted of two rows 6 feet apart, the first having sixty-seven piles which were 10·79 feet from centre to centre of each pile, whilst the other row of piles, in number one hundred and thirty-two, further down the stream, were placed alternately at intervals of 7·54 feet and 3 feet 3 inches. The first line of piles commenced from the slope of the right shore running to the counterfort of the left bank; the second line had its axis 2·14 feet from the foot of the slope of the counterfort on the right side. These piles were strengthened by cross-pieces and waling-timbers, which, being covered with planks, formed a service-bridge during the construction of the works. Between the two rows of piles, beds of solid hurdling were then sunk, each hurdle consisting of eight fascine bundles, cut and spread lengthways, having a bundle laid at the thinner end to stop the gravel, and the whole being secured by tarred ropes fixed on seven poles, three laid lengthwise and four crosswise, so that one pole being longer than the other, abutted against two piles of the front row, with spaces left for every two piles of the other row. By this means the whole space thus marked out between the piles was solidly filled up; smaller bundles being rammed into the empty spaces around the piles. Sand and gravel, and about seven thousand one hundred smaller solid baskets were also thrown in above the stream, to stop up all fissures and help to

consolidate the whole. In this way two hundred and eighty-one hurdles were sunk for each layer, and when the work had arrived at the level of 8·12 feet above the bed, the whole was weighted with broken stone, and was built up to the full height; it was then covered with additional broken stone and gravel, to the extent of 10,839 cubic mètres, or 382,725 cubic feet. At the same time a bank, or facing of earthwork which was covered with coarse gravel, having a slope of 3 to 1, was laid up-stream to 2·6 feet above low-water level, the fall being 6·17 feet, and then ordinary fascine work was made use of to connect the counterforts of the left shore with the root, or commencement of the hurdling. By this means two banks, or portions of the dam were secured, viz., the general fascine base, and the bank resting in front of it, sustained by the piles; solid benchings were then fastened upon these, formed with floating fascine work of bundles, commencing from the shores and laid closely together, crossing each other diagonally. These were well picketed and fastened down, being cut into the banks full 25 yards, and having vertical hurdlings at regular distances fastened upon every second bedding. They were sunk by degrees as each new bedding was added, the third layer being much broader than the rest, so that when sunk, it overlapped the two lower ones and formed a kind of footing for the superstructure. When sufficiently solid and firmly fixed, the whole was weighted with additional gravel and stone, and thus the works from each shore proceeded until they nearly met, when a continuous floating body of considerable dimensions and fastened to each portion, was sunk and worked up in a similar manner, but with greater haste, the entire front slopes and heads being further preserved by fascine bedding, thrown in and secured over them. A front gravel bank up-stream was then thrown in, and the whole section was worked up to high-water level with clay and fascine covering, the down-stream face being further armed with rock work. This work has answered completely, and the old arm of the river is nearly filled up, although it was formerly from 22 feet 9 inches to 35 feet 9 inches deep. Half the expense was saved by using baskets instead of stone, and the total cost was 156,383 francs or £6,255.

The regulating, or dividing weirs at the junction of smaller streams with the Rhine, are constructed with stone similarly to those in England. In addition to the dams before described, shore-preserving works are carried out to a considerable extent, consisting of parallel walls and spurs. If the line of channel agrees with the banks in direction, and the width of the stream is the one most suitable for the water level, the parallel walls are made use of; but if

the stream differs to the extent of 65 feet or 97 feet 6 inches, then spurs are preferred for the purpose of warping up. Beyond this extent sunken dykes are constructed, extending much further into the river. The parallel walls are constructed with solid fascine work, well pegged into the ground, and covered with stones averaging 400 lbs. each, with a slope, when finished, of 2 to 1 towards the stream. Counterforts are laid in behind, at intervals of from 20 yards to 30 yards. The whole work is carried up to high-water level and is planted. The spurs here, as well as on other parts of this river, have been tried with various inclinations against the stream. Formerly they were fixed here with an angle of 45° up-stream, which was then considered very suitable for the locality, but experience has since recommended the right angle, and its use has shown, that there is less destruction of the banks, with a greater amount of warping, and this in proportion, within limit, as the distance between the shore and the extreme point of the spurs, or alteration of the current, was increased. M. Desfontaines considers the extent of shore preserved by a given spur, to vary in gravel beds, as the co-sine of the angle, at which it is laid, and introduces rectangular spurs, 146 feet to 162 feet long, and 22 feet to 29 feet broad, sloped off angularly at the extreme point down-stream, having strong roots and denticulated wings. These spurs will, in his opinion, protect an extent of shore equal to five times their own length, but they require continual repairs. The sunken dykes, or weirs are formed similarly to dams, being about 195 feet long, and running square out from the shore, with a counterfort at the end in the line of the current, extending 81 feet 3 inches from the centre up-stream and 48 feet 9 inches down, well sloped off with heavy blocks of stone. This counterfort is carried up to high water, whilst the body of the dyke is only just above ordinary level. It must be added, that the lands adjoining the banks and liable to be flooded, are laid to a regular fall, so as to throw off the water as it recedes.

The Prussian part of the river is the rocky district, through the greater portion of which it has been only found necessary to quarry the slate stone from the shores, and to construct shore walls, in a similar manner to the Cornish field walls, laid dry. They are from 1 foot 6 inches to 2 feet thick at the top, and batter outwards 1 to 1 with a backing of 1 foot to 1 foot 6 inches of screened gravel, the top level varying from 5 feet to 10 feet above low water. No sand is permitted to remain immediately behind the stone work, and the footing is well let into the bed, sloping landwards. The straightening cuts of this district are immediately above and below Mannheim. One near that town, undertaken in 1836, has failed on account of a

stone bottom being found 3 feet below the water level, and is useless, excepting at high water. Near Worms, Oppenheim, and Erfelden, they have, however, been carried out successfully; but, in every case, they were found to be of great advantage, when the old channels were closed up, so as to bring the full force of the stream to deepen them, the sides of the new cut being artificially preserved. Near Bingen, there is a portion of the river, where, in 1830, the rocks were blasted under the direction of M. Van den Bergh, so as to obtain a sufficient passage for steamers and other vessels.*

Lower down the stream, near Coblenz, the later improvements on the Moselle are well deserving of attention; and the following translation of a Paper by M. Van den Bergh, under whom the improvements on the Moselle were undertaken and carried out, may be suitably inserted here.

"The Moselle is a mountain river, navigable for large craft, between Metz and its junction with the Rhine at Coblenz. Above Metz, it is only serviceable for light barges. The lower portion between Trèves and Coblenz, on which by far the larger number of vessels ply, is rendered of greater importance to the navigation by the addition of the Saar, which falls into the Moselle above Trèves. This portion is 211,344 yards or 120 miles 143 yards in extent, and has a total fall, when the stream is low, of 217 feet. This fall is, however, very unequally divided, as in various places, knolls, or banks exist, extending across the bed of the river, damming up the stream and causing it to rush over them, with a sudden fall, and increased velocity. These banks have been formed partly by the too great breadth of the river, and partly by the number of curves in it; or, they may, perhaps, have originated from the coarse rocky gravel, brought down by the rivulets from the mountains, settling and becoming consolidated. During the seasons at which the stream is high, these banks produce scarcely any effect on the surface of the water, and the level of the stream is then more, or less continuous. In summer and autumn, when the Moselle is usually at the fullest, the depth of the water is from 2 feet to 3 feet; but in the shallows, on the banks above mentioned, it was, before the improvement of the river, only 1 foot 8 inches to 2 feet in depth. In very dry summers, there is scarcely 1 foot of water in the stream, and the

* The operations carried on at Bingen are fully detailed in the original Paper and proved successful, but it is not considered desirable to give them in a printed form, as so many improvements in blasting have more recently been made.

depth on these banks is then reduced to 6 inches. With a depth of 2 feet, the total quantity of water in the Moselle, amounts to nearly 3,895 cubic feet, and with a depth of 3 feet 6 inches, it may be reckoned at 7,345 cubic feet. In the latter case, the greatest velocity of the stream on the bank below Kochem, was formerly 10¼ feet per second, the mean velocity being about 3 feet per second; whilst the inclination amounted, on the average, to 1 in 2,983. The general breadth of the river may be computed at from 497 feet to 558 feet. The bed of the Moselle between Trèves and Coblenz, consists, for the greater part, of heavy coarse gravel, and but rarely of sand. There are, however, several places in which the bed of the river consists of rocks, rising occasionally above the surface of the water, and over which there generally exist powerful currents and eddies. The sloping hills along the valley of the Moselle, consisting principally of clay-slate rock, rise to 600 feet and 900 feet in height, and are often very precipitous.

"In the proposed improvements of the stream, the principal object aimed at, was, to increase the depth of water over the banks, and by extending the fall over a greater length, to reduce the heavy rush of water. In order to effect this, it was of the utmost importance to devise the best means for removing the causes of the shallows; and where these originated in an excessive breadth of the river, or in several arms caused by islands, it was proposed either to reduce the breadth by projecting works, or to close up the superfluous arms. In determining the arm of the stream, which should be left open, it was necessary to be guided by the upper and lower direction of the stream; and on this also depended the manner in which the contraction of those portions of the stream, which were considered too broad, was to be effected. Where the branching out of the river was caused by sudden and sharp curves, it was deemed necessary, in the first place, to straighten them, for which purpose, certain projecting works were carried out, from the concave shores, whilst at the same time, the extent to be acted upon, on the convex shore, was limited by arming, &c. In cases, however, where the cause of the shallows was to be sought in the junction of rivulets, and where they arose from the settling of the heavy gravel, brought down by the minor streams, it was thought desirable to separate the waters as far down-stream as possible, by regulating, or division banks, the entrances being fixed at spots, where the river was either sufficiently narrow, or the convex shore sufficiently advanced into the stream, to cause such a current, as would carry off all the heavy material in suspension, to places lower down, where it was desirable to create a shore. Throughout the whole of the works, it was determined, that

the gravel which it was intended to make use of in construction, should be taken from the banks in the river, which it was thereby sought to loosen, with a view to render it more easily acted upon by the stream when altered. In places where the bed of the river consisted of rock, the passage was improved, partly by blasting, and partly by considerably contracting the width of the river, thereby raising the water level above the rocks and gaining a greater depth for the passage. Proceeding on these principles, the object of all the works was to form a regular course, and artificial shores,* thereby confining the injurious action of the stream within certain bounds, by which means it was prevented from departing from its improved channel.

"The course according to which the shores were to be constructed, or the bed of the river contracted, being once decided upon, it was carried into effect, principally by a system of spurs laid against the direction of the stream, at an angle of 70° to 75°, being placed at such distances from each other as to protect the intervals of shore. In carrying out this system, great care was taken to allow the works to diminish gradually, so as to avoid any abrupt contractions. The distance between the spurs, on convex shores, did not, in general, exceed the regular breadth of the river, which was about 124 yards; whereas, on concave shores, they were usually laid nearer together, in order to obviate the danger arising to the navigation, from the rush of the stream between these spurs. At the commencement of the works, they were constructed partly by means of fascine work, and partly by rock work. Long and manifold experience has, however, proved the superiority of stone building, for this locality, as not only enduring much longer and keeping better together, but also being much less expensive, inasmuch as stone can be quarried almost everywhere on the banks of the Moselle, and the necessary gravel is found in every part of the stream. Where the currents were rapid, the foundation of the spurs was formed by throwing in heavy stones, between which however a suitable quantity of gravel, (amounting generally to about one-fourth of the whole mass,) was added, in order to fill up the interstices. As soon as the foundation reached low-water level, the body of the construction was worked up with heavy gravel, and then faced with regular stone work, laid close and domed. For the sake of economy, and in places where the current was not strong, the foundation, instead of being solid rock work, was built hollow and filled

* It must be borne in mind, that throughout the whole extent of the Moselle, the beds and shores are firm and solid.—*Translator.*

up with gravel. This mode of construction was found to be sufficiently strong and durable; but it required very good work for the purpose. With regard to the dimensions of the spurs, it may be remarked, that the crown, consisting of stone facing, was generally fixed at 6 feet in breadth, having a batter on both sides of from 1 to 1, to 1½ to 1; the thickness of the facing being from 1 foot 3 inches to 1 foot 6 inches. The crown was rounded off on the upper surface, and at the foot a benching was left, 2 feet wide, which formed the upper surface of the foundation walling, which, in its turn, was sloped off on each side from 1½ to 1 to 1½ to 1. All these dimensions required to be modified, according as the stream was more, or less rapid, and the works themselves more, or less exposed, but they may be considered as average quotations. The crown of the spurs was laid about 2 feet above low water, sloping up shorewards, about 3 inches, or 4 inches in 12 feet.

"The weirs for damming-up arms in the stream, were constructed in the same way as the spurs, the foundation work consisting of the heaviest stones. These weirs were, for the most part, made to batter very slightly from the horizontal on the down-stream side, whilst on the up-stream side they were nearly perpendicular. In closing these weirs, whenever the current was exceedingly rapid, baskets were used, from 3 feet to 4 feet in diameter, and from 7 feet to 8 feet high, filled with gravel and broken stone, and pierced with poles, the latter being for the purpose of preventing any sliding; and these means proved perfectly successful. The upper portion of the weir was similarly constructed to that of the spurs. Generally, however, the width of the crown and the thickness of the facing, were made stronger in proportion as the rush of water was more considerable. In order to throw off the current from the shores, where the weir closed in, the centre portion of the weir was made lower in elevation, it being circular on plan against the stream, to give additional strength.

"When the first improvements were commenced, a contraction of the river to the extent of from 124 yards to 149 yards, was considered sufficient for the channel; it proved, however, that the width left was still too great, and that a further contraction was necessary, to move forward the heavy gravel. On this account the works were, for the most part, extended, and according to local circumstances, a width of not more than 103 yards was left free for the main stream. But, even this contraction did not suffice for the lowest water-level; and hence lighter works were added to the extremities of those already executed, projecting further into the stream, than the original line laid down for the improvements, still further re-

ducing the channel to 62 yards, which diminished width was eventually found to afford sufficient depth of water. These lighter works were constructed chiefly of fascine work. In some cases, before the side streams were closed up, it was necessary to dredge the main course above and below the islands, so as to open it for the shipping. In general, no interruption in the navigation took place, as immediately on the closing up of the one arm, the other obtained a sufficient depth of water. At first, the sands accumulated lower down-stream; this, however, rarely lasted long, for with a view to remove more quickly the inconvenience caused by it, light works were erected on these shoals, which served to contract the stream, and by the increased velocity, helped to carry away the sands and end in their own destruction. In places where the haulage track required to be laid across to an island, the upper and lower embankments were laid as nearly parallel to the course of the stream as possible, in order to allow the horses, employed in drawing the barges, to pass over without detention. On this account, the tracks were constructed with a width of crown of at least 12 feet, and slopes flatter than the other works, so as to prevent the horses from being precipitated downwards. At the junction of rivulets, works were introduced for the purpose of closing up the old entrances and leading them further down, because they had narrowed the Moselle itself, in one, or two cases, to 41 yards in width, from the deposit of gravel, which they had not the power of carrying off. These works have been previously mentioned, as regulating, or dividing works. The fall along the minor streams, more immediately at their junction with the main river, is but moderate, and therefore, the heavy gravel, which the rivulet, precipitous at its commencement, brings along with it, is here deposited, before it finds its way into the Moselle. This, as a matter of course, requires to be removed at stated times.

"Where the whole bed of the river consisted of rock, and where a passage of 29 yards in width had to be formed, it was done by blasting, and in cases where also spur work had to be laid on contiguously, an additional parallel work was constructed along the navigable stream, so as to prevent vessels from being drawn in between the spurs. At the lower end of this parallel work, the width of the Moselle was contracted to nearly 54 yards, in order to preserve the necessary depth of water flowing over the rocks. As yet the various works undertaken for the improvement of the Moselle, have completely answered the most sanguine expectation. A very important amount of banking and warping, has been effected between the several works and in the arms which have been closed

up; the depth of the river has been so much increased, that even when the water is low, vessels can conveniently pass with a loading deeper by at least 6 inches than formerly; and the dangerous currents have been obviated.

"The greater portion of the works have been already constructed, but it will still require three, or four years before they have entirely effected the object for which they were designed."

From the foregoing account of the works on the Moselle by M. Van den Bergh, it does not appear, that the system of growing certain species of brushwood in the stream, found so efficacious on some of the French rivers, for damming up the water and assisting the navigation, has been at all introduced. The reason for this will be found in the quantity of heavy material which the Moselle carries in suspension, and to which it would be very objectionable to offer any resistance.

Leaving the Moselle and following the course of the Rhine, it may next be mentioned, that from 1826 to 1830, the shores from Coblenz downwards, were mainly preserved by fascine bedding and fascine spur work which then answered exceedingly well. During this period steam navigation was only being gradually introduced on the German rivers, and did not fairly come here into action, until the removal of the rocks at Bingen; since then, however, these vessels have so increased in number, that eight, or ten are now making the passage daily, and it has been found, that the swell created by them is so powerful, and that the waves are produced in such rapid succession as to injure the fascine works very considerably. Stone, however, being very cheap, and the ground extending below Düsseldorf being firm gravel, they have thus far been re-constructed with rubble walling, or at least covered with rock facing.

Through Holland the soil changes into mud, and fascine work has, therefore, been retained, for the sake of producing adhesion and preserving the ground from working out. The Dutch maintain, to this day, their preference for fascine work, as being most suitable for treacherous ground, in addition to which they are guided by the high price of stone. Above Düsseldorf, fascine work well planted, is used where time is an object, and a temporary repair only is required.

Throughout the distance between Cologne and Düsseldorf the shores are preserved by stone walling, built after the same manner as those already described above Coblenz; the stone being readily found on the shore. In reference to spur work, it must be remarked,

that until the year 1788, the Engineers of this and the lower district, endeavoured to improve the Rhine channel by a system of down-stream spurs, which were afterwards altered into isolated perpendicular ones, and in 1811, re-altered by Wiebeking to the former, with additional return-arms at their ends. Of these a very considerable number were constructed at a great expense, but nearly all have since been swept away. In the mode of construction, Wiebeking insisted on the following points:—That the spurs should be laid on at a very low water-level, to remove the eddying from the channel as far as possible;—that spurs should not be used, unless the stream had a velocity of, at least, 2 feet per second, or carried a very great quantity of material in suspension, in which latter case, he preferred isolated perpendicular spurs:—if there was little material in suspension and low velocity, he recommended all the works to die off into the beds and shores, and to offer as little resistance as possible;—he further considered, that spurs pointing down-stream had the disadvantage of throwing the current into the shore below, and he therefore added guide-arms at their extremity;—and lastly, he preferred triangular and circular spurs, when there existed tidal action, and where the ice came down in large masses.

Proceeding down the stream, the next object of engineering interest is the dam 1,140 feet in length, erected by Wiebeking in 1790, at the Island of Honneff, close to Bonn, for closing the side channel, and constructed with fascine work on the old plan. This structure was laid on close to the current, at the apex of the island, and not set back according to the French system. It does not appear to have answered very well for sanding up the channel, as in 1847, the arm was still of a considerable depth. It has, moreover, cost a heavy sum to keep it in repair, on account of the great wash it has to sustain. The velocity of water under which it was executed, was 6 feet per second. The dam was closed by sinking large fir-trees with ropes, to which fascine baskets, 18 feet long and 3 feet in diameter, filled with stone, were firmly fastened, and over these twenty-two immense solid fascine masses were laid, well weighted with basalt-gravel and hurdling. The effect of this work, when completed, was to deepen the stream 3 feet.

A little lower down the Rhine the outlet of the Sieg presents itself, which appears defective; for instead of entering the Rhine at an acute angle downwards, it meets it rather up-stream, thereby producing several shoals close to its mouth. It would seem as if the original entrance had been lower down, at Mondorf, and that in 1760 it underwent a change, a circumstance greatly to be regretted, inasmuch as, if the waters of the Sieg were to be led back again to

their former channel, and all the side arms closed up, it would be improved.

Near Düsseldorf there are numerous and sharp curves in the course of the river. M. Wallbaum, the resident Engineer in charge of this portion, has confined himself simply to defending the concave shores, but has not as yet attempted to direct the course of the stream. This improvement, M. Möglingen, who has been already quoted, is anxious to see carried out on a similar plan to that employed on the Moselle and the Ruhr, preferring, however, to lay on sunken dykes, built up to only 3 feet in height, but of considerable length and with a steep inclination shorewards; he admits, however, the enormous expense of such works. M. Wallbaum's main works in progress are the following, using fascine work and rock work in conjunction. The shore covering, or arming at Flehe, on the right side descending the stream, consists of a wall, or body of fascine work, built up to 10 feet of water, at which level it is 6 feet thick, with an outer batter of 1½ to 1, faced 1 foot 6 inches with basaltic stone, extending over the top, the largest stones being laid at the toe of the slope, and the whole, behind, being filled up with gravel and sand, sloping towards the river on the surface and well planted.

At Grimlingshausen, on the opposite side of the river and lower down, the shore walling is of increased thickness, forming the slope of the haulage track. It is also faced with basaltic stone of additional strength, having a level footing 2 feet wide at the base, stopped by oak piles and fascine work; the top being secured by a walling-piece, or coping on dwarf piles, to prevent the ropes and chains from tearing it away. The road is laid on at 16 feet level above the bottom. In consequence of the flood of 1846 having carried the old track completely away, this work and its subsequent continuation past Herd, is nearly 5,280 yards long, and cost £11,000. The new track at Herd has an inner slope of 2 to 1 faced with stone. The section of the track road laid across the Zons hollow, is also similar, and it may be remarked, that wherever stone is used along this district, it is laid with a backing of sifted gravel, free from any sand, or dirt. At Düsseldorf itself, a considerable portion of the quay, forming part of the old fortification, was found, in 1846, to be undermined by a strong current, and is, at present, almost in ruins. Immediately in the front is a considerable depth of about 70 feet. Above the quay wall just mentioned, is a very excellent embankment wall, made with basaltic stone 5 feet to 6 feet thick, the slope being 2 to 1 from 50 feet below low water with a backing of clean gravel, upon which, at the level of 6 feet, a pavement is laid, and then another stone slope similar to the first, 1 foot 6 inches thick with a

batter of 1 to 1, reaching to 26 feet level. The town itself lies on a concave shore, and the convex side in front has, of late, very much increased. To improve this, M. Möglingen has brought before the proper authorities, an old proposal for cutting a straightening channel from Flehe to the town. Whether this proposition will now be carried out, or not, is doubtful. There are, however, near this town, extensive works, which will require to be in a great measure renewed, if the present course is to be retained; so that, perhaps, as the expense in both cases must be heavy, the straightening of the river may be preferred, and it would certainly assist in carrying down the ice, &c.

Not far from Duisburg is the Ruhr. The navigation of this stream has been greatly improved by the same means as were used on the Moselle, and with great success. It has weirs and locks in addition, on account of its great velocity and fall. Below this to Emmerich several straightening cuts have been made in the stream, for instance at Wesel, Xanten, and Rees, and extensive fascine dams have been erected, for closing up former arms. Beyond Emmerich is the famous Byland cut, or canal, which is about 480 feet wide with an average depth of 5 feet. When it was first made to the extent of 6,000 feet, the shores and bed being of light clay and mud, gave way under the strong action of the water, and were obliged to be artificially preserved. This work, including a new outlet at the Yssel near Arnhem, which latter was about 4,380 feet long and 180 feet wide, cost £100,000. The effect produced was an increased velocity in the stream and a fall in the water level, before Arnhem, of 12 inches to 20 inches.

On entering Holland the Pannerden Canal, at the first division of the Rhine below Lobeth, claims attention. It was originally cut, by Brunnings, in 1742, and enlarged in 1780, being made 618 feet wide, or half the size of the Waal. Great care and attention were required in forming the separation and shore works. The separation work at the crown, was commenced at 8 feet Pannerden level, and finished rising to 19 feet level at the root. At first this work did not answer, and required lengthening as the bed changed, but it is now in a good condition, having generally about 9 feet water, the low-water level being 4 feet to 5 feet. Down to this part of the Rhine there is very little difficulty connected with the drainage of lands, but throughout the whole of Holland to the sea the very slight inclination of the country, or variation of level, renders it by no means an easy task to perform, as it depends on the level of the water in the rivers and sea, whether the sluices of the canals can be opened to advantage. These waters, during spring time, are much higher than most of the

polder lands, so that the method adopted for getting rid of the inland drainage water, is that of pumping by wind power applied to the Archimedean screw. The actual drainage water is kept as separate from the main navigation as possible, by being led, or pumped into canals, which terminate with sluices* at the river, or at the sea, so as to let out the internal waters into them, whenever practicable, and yet to keep out the flood waters brought down from Germany during the spring. It will be perceived by reference to the Table already quoted, containing the velocities of the Rhine, that between Holland and the sea the stream travels at the rate of 3½ feet to 2 feet per second, with 6 feet water level, which is quite sufficient to move stones of the size of hens' eggs, and it will, therefore, be no wonder if the Dutch, not having cause to fear any floods from their own country, should wish to keep out the river waters, considering that the beds and shores are continually liable to change under its action; indeed, even though the stream is kept in its channel, it is only by the greatest activity and attention, that the damages are capable of being repaired.

Throughout the Dutch Rhine, the Waal, the Leck, and the Meuse, above the reach of the tide, the system of shore building consists of fascine spurs, placed more, or less perpendicular to the shore, and of extensive arming, constructed with fascine work, covered with basaltic stone, or bricks. The shores are well planted, particularly the one on the right, as it is much acted on by the westerly wind. The spurs have their roots laid on at ordinary water-level, with a fall towards the channel of 1 in 72 to 1 in 200: the crown is 16 feet 3 inches wide, and the sides batter 1½ to 1 against the stream and 1 to 1 down the stream. The length of these structures varies from 217 feet to 455 feet, and they are laid on at intervals of two, two and a half times, and three times their length. The fascine walling, or arming along the Dutch shores, is of similar construction to that described at Düsseldorf, being made with a fascine body to 8 feet 6 inches water-level, with a slope of 1½ to 1 faced with brick; then a benching 20 to 1 and a further slope forming a dyke of 4 to 1, the crown of which is 16 feet to 18 feet wide, and at the fixed level running backwards with an inclination of 2 to 1 and resting on the fields. The regulating, or separation works, are constructed with heavy stone facing, resting on large solid fascine masses, having extensive wings. Before closing this part of the subject, it may be stated, that there still exists an old Guelder law, with regard to spurs, by which it is ordered, that no spur shall go further into any

* The level of the cills of the larger sluices is about 20 feet below A.P.

river than one-third of its breadth, that the clear channel of the Waal, the Meuse, and the Yssel shall be in the ratio of 6, 2, and 1, and that any river having less breadth than the least of these, shall have no spurs at all. Wiebeking, speaking of the rivers in Holland, says, that where there is a velocity of 2 feet per second, he considers, that spurs ought not to be more than their length apart, the distance being increased as the velocity decreases, to the extent of four times their length, beyond which he would use arming. Below the tidal action, all the works are formed with fascine bodies called 'sink-stücke,' each layer being 4 feet to 6 feet thick, and 72 feet by 36 feet area, very heavily weighted, and faced with stones. The dykes against the sea have a general slope of 8 and 10 to 1, their crown being carried up to 3 feet and 5 feet above the highest known flood level; below low water their slope is about 90 to 1. The Dutch consider upright walls better suited to bluff shores than their own. On examining the last portion of this river, namely that below tidal action, it must be admitted, that it is in an improper state, being full of sandbanks, and shoals, and divided, as already stated, into numerous arms. Before giving the experiments of Blanken and Bolstra on the tides, the following facts may be adduced to assist in explaining their action.

The tides in rising from the sea* pass along the south channel at the Briel, over the bar at that place, up the Old Meuse, and by way of Dordrecht, to Bommel, and also at the same time, up one side of the New Meuse by Rotterdam to Vianen. From Helvoet-sluis and the channel at Goeree, the tide passes along the south side of the Haring Vliet and River Flakkee, also along the south side of the Hollands Diep to Dordrecht. The ebb stream, on the contrary, moves downwards from Dordrecht, through the Noord by the New Meuse, and the North Channel by the Briel to the sea, as well as from Dordrecht through the Oude Wiel, the Krabbe, along the north side of the Hollands Diep, and the North Channel at Helvoet by the Quaks Diep to Goeree and the sea. With respect to the time of the tides, it has generally been found, that it is high water, at the same time, at Rotterdam and Willemstadt, but the tide continues to flow for two hours† after this period, up the Old Meuse and Merwede by Dordrecht to Bommel, whilst at the same time, it has commenced ebbing at the Briel. Blanken states, in his Prize Essay, that along the

* The tides run to the south on the English coast of the Channel, but northwards along the Dutch and Belgian coasts.

† At sea, the tide at the upper part of the Channel continues flowing up three hours after high water, and flowing down three hours after low water.

Haring Vliet, the tides run up from one hour to one hour and a half longer along the south shore than along the north shore, and that the average velocity of the ebb along the Quaks Diep amounts to 2½ feet per second. Wiebeking says, that he noticed it ebbing on the north shore of the Haring Vliet full three-quarters of an hour before it turned on the south shore, and adds, that on the Elbe the same difference of time exists, but with reverse shores, whilst on the Weser it ebbs on the west side, when it is still rising to full tide on the east. From information received on the spot, it appears, that at the Briel with a strong wind from the north, and afterwards from the west, the water level is considerably raised, insomuch, that on account of the breakers at the bar, ships have been retarded for two weeks at a time. This depth of back water is very dangerous, as it presses heavily on the dykes. The bar itself is better of late years, more particularly since the heavy descent of ice during 1845 and 1846. At the Briel the real channel is very narrow, and is only 12 feet deep at low water, with the bar on each side scarcely 3 feet under water. At ordinary high-tide there is a depth of 12 feet of water over the bar. The total breadth of the mouth, is now only 5,190 square feet across, whereas in 1606, it measured 11,865 square feet. Near this place the Canal of Voorn has been constructed to assist the shipping. Generally speaking the tide is four hours rising, but nine hours running out; with a westerly wind, however, a material change takes place.

The main stoppages by ice occur at Vianen and Krimpen on the Leck, and at Hardinxvelt on the Merwede. The present island of Goeree consisted, in the year 1600, of two islands, but when the Biesbosch became opened, an alteration in the currents took place, and in course of time, both became united. In 1732, in front of Helvoet where the sandbank now lies, the depth of water was from 25 feet to 40 feet. In fact, the coast of Holland is continually changing, in a greater, or less degree, and during the sixteenth and seventeenth centuries it rose to the extent of 20 feet, mainly in consequence of long-prevailing westerly winds. It has been stated, that the north-westerly coast is again receding.

The following Tables may be interesting as showing the character of the tides on the Dutch coast and rivers, ascertained from actual observation:—

TABLE V.—Experiments of Blanken on the Tides, 1796, 1797, and 1798.

Places.	Duration of Flood.	Interval.	Duration of Ebb.	Interval.	Difference between High and Low Water.
	Hours. Min.	Min.	Hours. Min.	Min.	Feet. Inches.
At the Quay at Goederede	2 9	8	7 0	39	4 7
South side of the island of Goederede	6 10	17½	5 45	18½	7 10
In Helvoet harbour . .	3 40	43½	6 12	89	5 8
In Briel harbour . . .	3 18	29¼	7 38	33½	4 8
In Oltzensplaat harbour .	4 58	13¼	6 31	31½	7 1

At the south side of Goederede, it was 1 hour 12 min. earlier high water than at Oltzensplaat.
At Helvoet harbour, it was 1 hour 9 min. ditto.

Wiebeking states, that at Blankenburg, the difference between high and low water is 16 feet 5 inches; at Brouwershaven 8 feet 2 inches; at Goeree 5 feet 10 inches; outside the Briel 5 feet 4 inches; at Katwyk 5 feet 3 inches; on the Friesland and Groening coast 5 feet 6 inches to 7 feet 6 inches; at the mouth of the Weser 9 feet 3 inches; at Cuxhaven 9 feet 9 inches; and on the Mecklenburg and Pommern coast, no rise, or fall, and no tide.

TABLE VI.—Summary, given by Bolstra, of Distances and Slopes up which the Tide travels.

Length of Rise of Tide.	Height to which the Tide reaches on the River, above High Water at Sea.	Inclination of Slope from High Water at Sea to highest point of Tide on River.	Fall of Ebb Waters from the River to Low Water at Sea.	Inclination of Slope from Low Water at Sea to River Level.
48 miles	25 inches	1 in 117,590	85 inches	1 in 34,585 at low water in river.
44·3 „	40 „	1 in 68,245	95 „	1 in 28,734 at mean water in river.
40·9 „	57 „	1 in 44,210	114 „	1 in 22,105 at high water in river.

TABLE VII.—Experiments instituted by Bolstra for ascertaining the Average Rise of Tide and Ebb in the Old and New Meuse, and in the Merwede, during 1739, 1740, and 1741, reduced to A. P. Level.

Localities.	At Ordinary River Height.							At Low River Height.							At High River Height.						
	High-Tide Level above A. P.	Low-water Level above, or below A. P.	Difference between High and Low Water.	Rise of upward current at High Tide.	Ratio of Slope being 1 in	Fall of downward current at Low Water.	Ratio of Slope being 1 in	High-Tide Level above A. P.	Low-water Level above, or below A. P.	Difference between High and Low Water.	Rise of upward current at High Tide.	Ratio of Slope being 1 in	Fall of downward current at Low Water.	Ratio of Slope being 1 in	High-Tide Level above A. P.	Low Water Level above, or below A. P.	Difference between High and Low Water.	Rise of upward current at High Tide.	Ratio of Slope being 1 in	Fall of downward current at Low Water.	Ratio of Slope being 1 in
	in.	in.	in.	in.		in.		in.	in.	in.	in.		in.		in.	in.	in.	in.		in.	.
At the North shore of the Meuse Mouth	30	−24½	54½	.	. .	.	. .	33	−27	60	.	. .	.	. .	33	−24	57	.	. .	.	. .
Near the Briel	30¾	−20	50¾	¼	326,400	4½	54,400	33	−24½	57½	.	. .	2½	97,920	35	−19	54	2	122,400	5	48,960
At Maaslandsluis	31	−18	49	¼	691,200	2	86,400	33	−24	57	.	. .	¼	345,600	36	−15	51	1	172,800	4	43,200
Old Meuse, at Weelplaat	32	−16	48	1	216,000	2	108,000	33	−23½	56½	.	. .	¼	43,200	38	−10	48	2	10,800	5	43,200
Near Vlaardingen	32⅛	−15⅛	47⅜	⅛	216,000	⅜	108,000	33	−22½	55½	.	. .	1	72,000	36	− 9	47	.	. .	1	72,000
Schiedam	33	−14½	47½	⅜	237,600	1	158,400	33	− 22	55	.	. .	1	316,800	40	− 5	45	2	79,200	4	39,600
Old Meuse, near Roon	33⅜	−12⅜	46	⅜	221,400	2	73,800	33	−21½	54½	.	. .	¼	295,200	41	− 2	43	1	147,600	3	49,200
Near Rotterdam	34	−11⅜	45⅜	⅛	267,840	⅜	133,920	33	−21	54	.	. .	¼	178,560	41½	+ ½	41	½	178,560	2½	35,712
At the Yssel Mouth	34½	−10	44½	¼	817,920	1⅜	122,688	33	−20½	53½	.	. .	¼	306,720	43½	+ 5	38½	2	102,240	4½	45,440
Old Meuse, at Jansdam	35	− 9	44	⅛	124,800	1	93,600	33	−20	53	.	. .	⅜	280,800	44	+ 7	37	½	187,200	2	46,800
At the Leck Mouth	35	− 8	43	.	. .	1	100,800	33	−19½	52½	.	. .	¼	201,600	45	+ 9½	35½	1	100,800	2½	40,320
In the Noord, at Alblasserdam	35	− 7	42	.	. .	1	133,200	33	−19	52	.	. .	¼	266,400	46	+12	34	1	133,200	2½	53,280
In the Merwede, at Dordrecht	36	− 5	41	1	183,600	2	91,800	33	−18	51	.	. .	1	183,600	48	+17½	30½	2	91,800	5½	33,381
Near the Engel	43½	+11	32½	7½	26,880	16	12,600	37	− 5	42	4	50,400	13	15,508	61	+38½	22½	13	15,508	21	9,600
Near the Bassekil	48	+23	25	4½	32,000	12	91,800	41	+ 7	34	4	36,090	12	12,000	70	+55	15	9	16,000	16½	8,727
Near the Steinenhock	52	+31	21	4	28,800	8	12,000	44	+14	30	3	38,400	7	16,457	76	+66	10	6	19,200	11	10,472
Near Hardinxvelt	56	+41	15	4	27,000	10	10,800	45	+21	24	1	10,800	7	15,428	82	+76	6	6	18,000	10	10,800
				26		65½					12		48					49		100	

The above is in Rÿnland measurement, 1 foot being equal to 1·03 foot English.

TABLE VIII.—Duration of the Ebb and Flood at the average height of the Weir, (at the time of New and Full Moon,) in the Meuse and the Merwede, as determined by Bolstra.

Localities.	Time of Lowest Water.		Time of Highest Water.		Duration of Flood.		Duration of Ebb.	
	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.
Mouth of the Meuse, North Shore	10	8	2	32	4	24	7	36
Near the Briel	10	40	3	0	4	20	7	40
Maaslandsluis	11	2	3	20	4	18	7	42
Old Meuse, at Weelplaat	11	40	3	44	4	14	7	46
Near Vlaardingen	11	30	3	52½	4	12½	7	47½
Schiedam	12	0	4	10½	4	10½	7	49½
Old Meuse, near Roon	12	19	4	27	4	8	7	52
Near Rotterdam	12	31	4	36	4	5	7	55
Mouth of the Yssel	12	58	4	57	3	59	8	1
Old Meuse, at Jansdam	1	10	5	8½	3	58½	8	1½
Mouth of the Leck	1	23	5	19	3	56	8	4
In the Noord, near Alblasserdam	1	41	5	34	3	53	8	7
In the Merwede, at Dordrecht	2	3½	5	54	3	50½	8	9½
Near the Engel	2	27	6	17	3	50	8	10
Near the Bassekil	2	43	6	34½	3	51½	8	8½
Near the Steinenhock	2	56	6	47	3	51	8	9
Near Hardinxvelt	3	8	7	0	3	52	8	8

With a strong west-north-west wind, the flood-tide wave rises to Bommel, 11 feet above the level of lowest water at Briel, or 6·1 feet above full tide, being up a maximum slope of 1 in 45,630, at a velocity of about 12 feet per second. Each period of tide is successively retarded 25 minutes 14 seconds.

TABLE IX.—Heights of the Crown of the Dykes along the Rhine, the Waal, the Leck, the Yssel, and the Meuse, above the Highest Floods at the respective places.

On the Upper Rhine, at Cologne, the crown of the dykes	is 3 feet above the flood of	1809.
,, ,, at Emmerich	is 3 inches ,,	of 1799.
On the Pannerden Canal	is 2 inches ,,	of 1809.
On the Waal, at Nymegen	is 1 foot ,,	of 1809.
On the Old Rhine, at Arnhem	is 2 feet ,,	of 1809.
On the Yssel, at Doesburg and Zutphen	is 2ft. 7in. below the flood	of 1809.
On the Leck, at Vianen	is 1ft. 1in. above	of 1799.
On the Merwede, at Gorcum	is 2 inches ,,	of 1809.

When the waters rise to 11 feet 10 inches above A. P. at Vianen, all the bells of the district are rung, to give notice of the danger.

The foregoing Tables permit an appreciation of the value of the several proposals, that have been made at various times, for the improvement of these rivers, the chief of which will now be noticed, it

being, however, premised, that the Old Rhine, by way of Utrecht and Leiden to Katwÿk and the North Sea, will not be brought under further consideration, because it does not, at present, materially affect the main stream, and also because the sluices and works upon it have been so well described in Mr. C. Manby's translation of the Chevalier Conrad's Paper as to leave nothing more to lay before the Institution.*

In order to effect the letting off the surface water of the Leck, various proposals have been suggested by Luloss, Bolstra, Redelykeid, Willichen, and other eminent Engineers, such as enlarging the Goudsche Yssel, with the addition of a new channel to the Zuider Sea, and constructing locks and sluices thereon, and also by enclosing the Linge River with dykes, and letting the surface water of the Waal flow into it; thereby reducing the general level by 2 feet. Nothing, however, appears to have been done, except building the dykes along the Linge. At length, about the year 1800, Blanken made a proposal for leading off the flood waters more quickly, and relieving the dykes. His plan, in addition to leading off by the Yssel to the Zuider Sea, proposed the construction of nineteen, or twenty fan-sluices in the dykes, and the flooding the low lands south of the Leck, and along the Yssel, to the depth of 10 feet, by which he also hoped to reduce the water level 2 feet, and at the same time to save the North Leck dykes, which, if once destroyed, would occasion the destruction of the most fruitful part of Holland. In 1815, his suggestions, which involved an outlay of £400,000, including seven sluices on the Lower Rhine and twelve on the Leck, each capable of carrying off 4,800 cubic feet of water per second, were partly carried out, by a fan-sluice being constructed below Spoel, and two others at Kuilenburg and at Gorcum. These were 24 feet wide in the chamber, and had their cills laid at 8 feet level below low water. They were furnished with gratings to keep off the ice, but did not answer the object aimed at, nor was Blanken's plan carried out to the full extent. In 1821, Baron Krayenhoff made two propositions to the Dutch government, which have been published. From the first it appears, that he proposed to make the Leck a navigable canal, with locks and sluices across the stream, and further, to cut the Yssel straight, and by raising the dykes 3 feet higher, to carry off the surface water in the quickest way to the Zuider Sea. From the second it seems, that he wished to improve the Lower Meuse by dividing and wholly separating the Upper Meuse from the Waal, both at Fort St. Andries and at Loewenstein,

* *Vide* Minutes of Proceedings Inst. C. E., vol. ii., 1842, page 172.

and thence to lead it, by a new cut, into its original channel, from Heusden to Geertruidenberg. Neither of these proposals have been carried out. M. Van Richtern subsequently submitted a plan, in some respects similar to that of Blanken, for flooding the lowlands and regulating the floodings generally, with the addition of considerably enlarging the Oude Wiel channel at the Biesbosch. Wiebeking, in his turn, further suggested the propriety of closing up the Oude Wiel channel and the other arms, in order to increase the flow of water towards the Briel, as also to construct groynes at the mouth of the river, for the purpose of deepening the channel and removing the shoals. About the year 1840, M. J. Scholten, in answer to the inquiry on the part of the Association for the Promotion of Science in Rotterdam, respecting the best means of improving the Dutch rivers, and preventing dyke breaches, &c., presented a Paper containing the following suggestions. The first, with a view to assist the Waal, was the construction of a side-cut with sluices, for the purpose of carrying off the surface water from Nymegen to the Upper Meuse, between Grave and Batenburg, then to separate the Waal and Meuse as proposed by Krayenhoff, and further, for the Lower Rhine below Arnhem, to cut a new channel and sluice, so as to lead off the surface water into the Zuider Sea, by a shorter and swifter course. For the Leck, he proposed to make and erect certain sluices in the dykes below Wÿk, to lead the surface waters into the Goudsche Yssel and flood the lowlands. For this Paper, M. Scholten received the gold medal of the Society, but the works proposed have never been carried out.

On tracing the various streams running through Holland, it certainly does not appear singular, that frequent ice-stoppages should take place in that country, whilst such occurrences are comparatively rare in Germany; for, as long as the Rhine retains its single course as at Emmerich, no obstacles, excepting elbows, stay the progress of the current seawards; but, as soon as it divides at the Waal and the Pannerden Canal, the evil commences and increases, according to the number of arms and channels lower down. It is generally agreed, that a river should have as few outlets as possible, in order to allow it the more effectually to clear itself, and that the tide should be admitted as far as possible, whilst at the same time, the action of the winds should be diminished; again, that the more the surface water of any river is obstructed, the more quickly the sand will accumulate, and also, that if a cut be made, it is usual for ice-stoppages to take place below it, so as to raise the water level above. It is also agreed, that if a cut be made, as capacious as the river itself, or be permitted to increase to that extent, it will soon

get beyond control, whilst the sand will accumulate rapidly, and that where openings exist in dykes, the ice gets into eddies and loses its velocity, and by degrees, closes up the passage below the opening, so as to raise the waters above. The question, therefore, to be solved with regard to Holland and the system followed there, in order to prevent breaches in dykes, and to save the better part of the country, (taking into account its weak marshy soil, and its incapacity to withstand any great force,) is, whether it be the better plan to relieve the pressure on the dykes, by cuts and new channels, and local floodings, at the expense of increasing the number of ice-stoppages, and at the same time, diminishing the velocity in the main river, thereby greatly augmenting its liability to accumulate sand. It is true, as already stated, that the rivers are, at present, in such a condition, that it must be very expensive to effect anything of importance; but, the question is of such vital importance to the port of Rotterdam, and the certainty of the mouth of the Meuse at the Briel, closing up, in the course of time, like that at Katwyk, if no improvement be attempted, is so evident, that it is very much to be regretted, some steps have not been taken, ere this, to prevent so great a flow of water, from passing out by the Hollands Diep to Helvoet. The Author directs the attention of the Institution to this subject, and submits the following points for the consideration of the Members:—

That the object to be aimed at, in any steps which might be adopted for improving the Meuse at Rotterdam, should be to protect and strengthen the shores and dykes likely to be operated upon by the alterations; to straighten all the curves on the Leck, so as to lessen the chances of ice-stoppages; to separate the waters of the Waal and of the Meuse as much as possible, and to lead off the former together with the Leck, into the sea by the Briel; to close all the Biesbosch channels, (at present divided,) excepting one, regulating the quantity of water; to close the Krabbe, the Noord, and the Spui, with sluice-gates; and, for the purpose of widening the outlet, to join the Island of Rosenburg to the main land at Vlaardingen, with the intention of causing the ebb waters to act upon this island, and by an increased velocity and an additional quantity of water, attempting to remove the bar and shoals.

The Paper is illustrated by an enlarged map of the Rhine from Düsseldorf to the sea, and a series of diagrams.

The Very Reverend the DEAN OF WESTMINSTER confirmed the accuracy of the geological portion of Mr. Jackson's Paper, and con-

gratulated the Members on the introduction of that science into the communications brought before them. He had always entertained the opinion, that Civil Engineers should possess, at least, such an acquaintance with geology, as would enable them from appearances and from the general formation, to judge what their works were likely to be based upon; and what materials would be best adapted and most durable, under certain conditions. The terms hard and soft, (as at present used,) were only relative, and without definite meaning; but when every Engineer was a Geologist, their employers would derive greater benefit from their opinions, for the terms would then be received in one and the same sense. It was notorious, particularly in the coal districts, that large tracts of land, which under what was considered competent advice, had been sold for small sums, had eventually, through the development of existing minerals, realised immense fortunes for their purchasers.

In examining the excellent geological map of the greater portion of Europe, by Van Buch, he was proud to observe, that the key-stone of the colouring and of the geological nomenclature was derived from England, in a great degree through the labours of Messrs. Dufrénoy and Élie de Beaumont, who had been sent hither to study the science, which the sections of the bold cliffs of the coasts of the United Kingdom were so well calculated to illustrate.

The Reverend Dean then examined and reasoned upon the maps of the ancient district, and the opinions of Von Buch and others, that in former ages no water came down into Holland in that direction, but that the channels had been commenced by disruption of the chain of the Taunus by volcanic action, and he concluded by giving briefly the results of his own researches in the district, which were fully confirmatory of the statements in the Paper.

Mr. FIELD, President, said, he had travelled up the Moselle in a steam-boat, and had noticed the ingenious manner in which the spurs were thrown out from the bank, in order to increase the depth of water in the channel, which was, in some places, still so shallow, that although the vessel was built of iron almost as thin as tin plates, and the engines were of the lightest construction, it was necessary to help it over the shoals with poles, by horses, and even by men pushing it; the voyage of 150 miles thus occupied full two days. Still the means adopted for the improvement of the river were very good and economical; and but for them, steam-vessels could not be used at all.

Mr. SCOTT RUSSELL observed, that the Dee, in Cheshire, somewhat resembled the Moselle, and similar spurs had been erected in

it; but he found, that although the channel was deepened immediately at the point, yet between the spurs, the channel became shallower than before, when they were placed at intervals of about four times their own length, in a stream whose velocity was about 6 feet per second. In this case, therefore, the spurs had not increased the facilities for navigation; because an augmented mean depth was not a real improvement, as the vessels must pass over the parts of minimum depth, and it was of no use to have one part very deep and another part very shallow. The question was, under what circumstances and to what extent, spurs would permanently improve and deepen the channel of a river? The resolution of this question from practical examples would be very valuable information.

Mr. CUBITT, *V.P.*, said, the object of the works on the Moselle was to render a rapid river navigable at all times, and spurs had been used, as the cheapest mode of accomplishing that end. In a river subject to floods at one period, and to a scarcity of water at another time, it was desirable, if possible, to make the section of the channel wide at the top for the floods, and to restrict it for times of drought; now as both these conditions were not possible, the only effectual plan was to divide the length of the river into ponds, by extremely long oblique weirs, with side locks for the traffic. These weirs should be of such extent, as that the sectional area of the space above the top of the weir, should be rather more than equal to the transverse sectional area of the stream, running bank-full at a short distance upwards from the weir; capacity was thus afforded for carrying off sudden floods, and sufficient depth of water was preserved for the navigation, without injuring the drainage of the land on the banks. This system had been practised with such success in the Severn, under his direction, that the navigation was now carried on uninterruptedly, instead of being, as was formerly the case, arrested for several weeks together by shortness of water, or by heavy floods.

The chief obstacle to a similar improvement of the Rhine and the Moselle, was the expense, which would be very great. Spurs had, therefore, been resorted to as offering, after ponds, the greatest probability of success; but Mr. Cubitt felt assured an uniform depth could not be so attained, and he almost received as an axiom, that if a little improvement could be affected by spurs, almost perfect regularity could be attained by ponds and side locks, so long as there was water enough for the lockage of the traffic.

Mr. SCOTT RUSSELL perfectly coincided with Mr. Cubitt's views relative to the advantages offered by the long oblique weirs. Another plan which had been tried in the Clyde, also presented certain

advantages. By throwing out a series of spurs from the shore, at intervals no greater than their own length, then uniting their points by dwarf walls only reaching a little above the level of low water, thus confining the stream at that time between uniform parallel walls;—it would be seen, that the water for the scour was no restricted, but was allowed to flow over the works on both sides, openings being left in the lateral walls to take every advantage of the scour-water. He considered this plan, or that of long weirs preferable to spurs, which he did not think very effective.

Mr. CUBITT, *V.P.*, said, the system employed on the Clyde, was well adapted for that portion of a river in which there was no fall at high water, as was the case between the Broomielaw and the sea; there, groynes, or spurs with the dwarf walls, aided by dredging and other improvements in the channel, had been very effective. That system would not, however, succeed so well in a river with a rapid current and heavy fall, and subject to floods, as the division into ponds with side locks. In fact, as had been argued in the discussion of previous questions, the Engineer must take into consideration all the circumstances and adapt his works to them.

Mr. SIMPSON, *V.P.*, said, a system had been pursued in the River Tees, of throwing out groynes, or spurs from the shore, and as the water held in suspension a large quantity of earthy matter, a deposit rapidly took place between the groynes, thus warping up and straightening the channel to such an extent, that now, vessels of four times as heavy a burden could reach the port of Stockton as formerly, and the depth of the channel was, he understood, tolerably uniform.

Mr. CUBITT, *V.P.*, corroborated Mr. Simpson's statement; the improvements of the Tees had been ably conducted by Mr. W. A. Brooks. A very curious effect had been observed after the groynes were constructed; the water circulated between them, cutting out a track in the form of a horse-shoe, and deepening the channel near the points, causing accumulations in other places. The ends of the groynes were then connected, leaving only a small opening in each for the scour water, and now the intervals were fast warping up. It must be observed, that the Tees was entirely a tidal river, the whole mass of water flowing alternately up and down, with a very insignificant natural stream which did not, therefore, require to be considered.

Mr. CROKER said, it appeared from the discussion, that two methods of proceeding were recommended, by which rivers might be made navigable. First, by means of long diagonal weirs with side locks and gates, the weir being of such dimensions, that all the water arising from floods might be discharged over it, without

causing inundations of the shores on either side; and secondly, by means of side embankments and facing to the original shores, thus in fact regulating the river, and contracting the sectional area of the stream, which being confined in smaller limits, would remove the shoals and sandbanks, and leave an unimpeded channel. The first method had been very successful on the Severn, and the second on the Clyde. The system of constructing spurs was deprecated as not only expensive but as not capable of producing the required effect, the bed of the river being, in general, deepened at the point of the spur, whilst the material thus removed was carried only an inconsiderable distance down the stream, where it was again deposited, in proportion as the velocity of the stream decreased; thus, in many instances, producing worse results, than the evils sought to be remedied. Now fully admitting these results, as well as the advantages and disadvantages of the several systems, he was at a loss to comprehend how such methods could be applied, with economy, to produce similar effects in rivers of such magnitude as that referred to in the Paper of Mr. Jackson; and it was much to be regretted, that no examples had been brought forward of the system of engineering adopted on similar large rivers, in comparison with which, those of Great Britain were insignificant.

Having been called upon to report upon the works of certain rivers in Hungary, where he had been engaged in the erection of the Pesth Suspension Bridge, he would offer a few remarks on the plans resorted to in that country, where the local circumstances of the different rivers varied considerably.

First, with regard to the River Danube, which rising in the Black Forest, not many miles distant from the Rhine, flowed in an easterly direction through Bavaria, Austria and Hungary to the Black Sea, received in its course the drainage from nearly 300,000 square miles of country, and between Passau and Rassova, no less than seventeen large tributaries, most of them navigable for vessels of large burthen. Owing to the vast extent of mountain country which discharged its waters into the bed of the Danube, it was subject to frequent inundations, and abounded in shoals of course gravel and sand, which offered the most serious impediment to navigation. During the course of the river through the mountainous and hilly countries, its waters were deep and rapid, but on emerging into the plain, they assumed a different character, dividing into many arms, and in several instances, assuming the appearance of vast lakes, the most extensive of which were in the vicinity of Vienna and a short distance below Presburg, where the river, including its numerous arms, was several miles in breadth.

The system till recently adopted by the Engineers of the country in order to render navigable those portions of the stream, was to construct spurs projecting into the main arm of the river, so that by deepening the channel, the water might continue to flow of considerable depth. In consequence, however, of the frequent occurrence of extensive floods, the channel thus formed never continued for any length of time, being always choked up in a greater, or less degree, and in many instances, after the subsidence of the waters, the spurs which had been constructed at a vast expense, were found to be totally washed away. In extraordinary floods, the water made a complete breach over the works, it being impossible, owing to the vast expense and time required, to construct embankments to retain the river in its swollen state, and owing to the foundations in such places being invariably composed of the débris deposited by previous floods. As the Engineers differed considerably as to the direction in which the spurs should project into the river, they were not always constructed in the same manner, some being at right angles to the bank, some obliquely up the stream, and some down the stream. These spurs were invariably of the most substantial construction, many being constru ted of whole timber piles driven in rows, the spaces being filled up by means of fascines and heavy rubble-stone and granite. Several hundred thousand pounds had been thus expended since the introduction of steam-boats, which took place in 1830, little having previously been attempted to control this mighty river. After sixteen years' experience, this method was abandoned, as insufficient to afford any substantial improvement, and recourse had been had, during the last two years, to a different system.

The plan now generally adopted was to reclaim the side arms, by constructing spurs, or dams, obliquely across the inlet immediately above; in a short time, the material held in suspension was deposited behind these dams, and as the spurs advanced into the stream, solid ground was made behind them. This plan had, therefore, proved the most effective, not only being less expensive, but more permanent; in several instances it had also been resorted to, to straighten the course of the river, the main channel now being, occasionally, formed through the side arms. A remarkable instance of the very great sinuosity of the river was to be found near its mouth, opposite to Czernawoda, where the river approached the Black Sea to within forty miles, but turning northwards, traversed one hundred and ninety miles of marshes and swamps, before it discharged itself. A favourable opportunity was here presented for diverting the course of the river, which might be accomplished at a comparatively small cost, by first excavating a fore-cut, or lead-channel, and leaving the

further excavation to the power of the stream, since a considerable fall and velocity could be commanded; a similar plan had been carried out with great success in the regulation of a river called the White Körös. Some time ago, the Austrian Government proposed to effect a junction at this point between the Danube and the Black Sea by means of a canal, but owing to political circumstances the project had never been executed.

With regard to the construction of weirs in rapid and shallow rivers, the plan alluded to by Mr. Cubitt had been adopted on the Altmühl, which flowed into the Danube about 25 miles above Ratisbon. The bed of this river had been converted into a continuation of the Ludwig Canal, which now connected the Main with the former river. The weirs were constructed in a similar manner to those on the Severn by the Bavarian Engineer, Von Pechmann, who first designed the line of this canal. Another important purpose these weirs might be advantageously made to serve, would be the driving of water-wheels for grinding corn, or other purposes, in those cases where the quantity of water naturally flowing down the river was more than sufficient to supply the lockage on the canal.

He would now allude to the Theiss, (one of the four great rivers of Hungary,) which rising in the Carpathians, flowed south through the fertile plains of Hungary, and fell into the Danube at Peterwardein. Owing to its small fall, the course of this river was very serpentine, and it was subject to very high floods, which at certain seasons, inundated the country for miles on either side. The natural morasses on the course of this river were very extensive, particularly in the neighbourhood of Szegedin, many being of no less extent than from 5,000 to 6,000 acres. In order to recover the large amount of fertile soil thus rendered wholly useless, it had been, for a long time, in contemplation to undertake works capable of controlling the waters of the Theiss, and they were eventually commenced, two years ago, under the able superintendence of Count Stephen Szechenyi, as Minister of Public Works in Hungary. One of the improvements would consist in excavating new channels, by which the course of the river would be straightened and the fall of the water be considerably increased. This would be accomplished by means of fore-cuts, the wash of the water being found sufficient to complete the section, notwithstanding the soil to be so excavated was, in most instances, a compact blue clay; when loosened, however, it readily dissolved in water. The other improvements would be obtained by extensive embankments and dams.

He would conclude by referring to the works which had been executed on the White Körös, which rising in the southern portion

of the Carpathians, flowed north through the Arada country and united its waters to those of the Theiss. This river, though of less extent than the Theiss, was similar to it in all respects, both as regarded its course, its small fall, and the nature of the country through which it passed, which was invariably a rich black clay, changing at some depth to a stiff blue tenacious clay, here and there intersected by rich beds of alluvial silt. The works necessary were, the diversion of the course of the river, with embankments and dams, the whole of which had been very successfully executed under the Engineer M. Joseph Bèszèdes. The system adopted for forming these diversions was, as proposed by M. Bèszèdes, the construction of lead-channels, or fore-cuts. The surface width required for the river was 90 feet to 100 feet, and the depth 15 feet to 20 feet.

In making the excavations, the material from the deepest cut, was thrown on to benches to be carried away by floods.

The summer, or dry season was invariably resorted to for excavating these channels, as well as for loosening the soil in the fore-cuts, which had already stood one, or more floods. The sides of the fore-cuts were always benched down perpendicularly, and the excavated soil was thrown upon these benches, sufficient having first been thrown out to form the necessary embankments on the surface. During the wet season, the floods were found always to remove the soil so loosened, and the saving of labour thus effected was very considerable. The length of these new excavated channels varied in length from 1,000 feet to 5,000 feet, the position of the new cuts being chosen so that the most circuitous parts of the river should be straightened. The land thus reclaimed was very fertile, being composed of a brown silty clay and fine sand.

Two, or three years after the new cuts were opened, the old bed of the river was found to be filled up to the depth of about 20 feet.

April 4, 1848.

JOSHUA FIELD, President, in the Chair.

The following Candidates were balloted for and duly elected :—

Henry Currey, Robert Hughes, Francis Cranmer Penrose, Francis Pettit Smith, and Sancton Wood, as Associates.

The discussion upon the Paper, No. 733, "On the Engineering of the Rhine, &c," by Mr. G. B. W. Jackson, being renewed, was extended to such a length as to preclude the reading of any other communication.

April 11, 1848.

JOSHUA FIELD, President, in the Chair.

No. 468.—"Description of the Bann Reservoirs, County Down, Ireland." * By John Frederic Bateman, M. Inst. C. E.

THE construction of the Bann Reservoirs was undertaken with the view of regulating the quantity of the water in the River Bann, and of more effectually supplying water-power to the flourishing and increasing establishments on its banks, particularly to those in the vicinity of the town of Banbridge, where, for about ten English miles, the river is closely occupied with extensive works of various kinds. Rising in the heart of the Mourne Mountains, in one of the wildest and most elevated parts of that beautiful chain of hills, and surrounded by abrupt and almost perpendicular eminences from 2,000 feet to 3,000 feet in height, the river is naturally and peculiarly liable to the greatest irregularity in its volume. This feature is materially aided by the bare and naked character of the mountains themselves, consisting principally of granite and grauwäcke slate, altered into a densely-compact and almost vitrified mass, by the action of the heat which accompanied their original upheavement, or by that of the numerous trap rocks and whin dykes which have since been protruded. There is scarcely anywhere a sufficient depth of soil, or peat, to retain by absorption, for more than a very short period, the rain that falls upon the hills, while the unstratified nature of the rocks, which are sometimes perfectly uncovered for the space of an entire mountain, prevents its finding its way, to any great extent, by cracks, or fissures into the bowels of the earth, to be discharged again in the form of springs at some lower elevation. Every shower, therefore, which falls upon the mountains is immediately and rapidly conveyed to the deep ravines and channels which form the beds of the rivers, and conducted by them into the open and comparatively level country, which commences at the base of the mountains.

* The first part of this Paper, relative to the construction of the Lough Island Reavy Reservoir, was read, June 29, 1841, (*vide* Minutes of Proceedings," vol. i. 1841, p. 168,) and would have been published at length in the 'Transactions,' if that series had not been discontinued. In order to render complete the account of these important works, it is now printed in connection with the "Description of the Corbet Lough Reservoir," the discussion upon which extended over portions of two evenings, but an abstract of the whole is given consecutively.—ED.

Devastating floods are thus frequently pouring down the channel of a river, which not an hour before scarcely afforded more water than was sufficient for agricultural purposes.

Greatly injurious as these sudden changes must evidently have been to the agriculturist, the mill-owner, and the public in general, still the mill-owners and manufacturers, who depended on the river for their supply of power, suffered the greatest and most constant inconvenience. The floods might occasionally commit ravages, but at other periods, for months together, the supply was inadequate to their wants. The increasing prosperity of the linen-trade, previously to the year 1835, and at the same time the increasing irregularity of the river, occasioned by the great extent of draining in the improved cultivation of the county, at length determined these gentlemen to adopt means for remedying the evils they experienced. For this purpose they consulted Mr. Fairbairn, who examined the country and advised the construction of various reservoirs, to impound the surplus water of wet seasons, to be applied in supplying the deficiency in times of drought. After this examination, in the spring of 1835, the Author received instructions to make the necessary surveys, to ascertain the capabilities and determine the extent of the reservoirs suggested by Mr. Fairbairn, who appeared to have fixed at once, with great clearness of view, upon the most favourable sites, and the result of the survey confirmed the propriety and importance of the works which had been proposed.

An Act was obtained, in the session of 1836, for the construction of the reservoirs, and for regulating the manner in which the money was to be raised, and the rates to be levied. It is worth noticing, that the principle of this Act differs essentially from those which are generally obtained for similar purposes in England. In the English Acts commissioners are appointed, consisting of the mill-owners and occupiers, for the purpose of carrying out the provisions of the Act, and the money is raised by the mill-owners and occupiers themselves in certain proportions, according to the number of feet of fall occupied, or the advantages received. Power is given to borrow the money upon security of the rates authorised to be levied upon the falls; but a difficulty is often experienced in obtaining the requisite money by this means, because nobody is willing to lend, until they can have the security of the rates, which cannot be laid, until the completion of the works affords the supply for which the rate is to be paid. It therefore generally happens, that the owners and occupiers are obliged to raise the money themselves, notwithstanding many of them may be both unwilling and unable to take so much of their capital from the ordinary channel of their business.

These feelings have certainly prevented the execution of many important works.

The Bann Reservoir Act constitutes the proprietors a joint-stock company, empowering them to raise the capital required in £50 shares, and to levy a rate on each foot of occupied fall, not exceeding £10 per annum, the interest of the money expended being limited, for the protection of the fall-holders, to 7½ per cent. per annum.

The fall-owners and occupiers had the first choice of shares, and such as were not taken by them were open to the proprietors of land, and to capitalists generally. But no fall-holder who was unwilling or, from pecuniary circumstances, unable to do so, was compelled to take shares; and in the event of a shareholder becoming embarrassed, his shares were disposable property. If it had not been for this principle the depression of trade, which followed the obtaining of the Act, would have been an effectual bar to the execution of the work.

The Act authorised the construction of three reservoirs, two large ones, to be placed near the sources of the river, as impounding reservoirs, and a smaller one a short distance above the town of Banbridge as an assistant, or auxiliary reservoir. Of the two impounding reservoirs, the largest was to have been at Lough Island Reavy, near Castlewellan, lying near to the River Muddock, a principal tributary of the Bann. It was to receive its supply by the aid of artificial feeders from a mountain district of about 3,300 acres in extent. The area was about 253 statute acres, and its capacity upwards of 287,000,000 cubic feet of water; and it was estimated, that the supply would be nearly sufficient to fill it twice in the course of the year.

The other situation chosen was at Deers Meadow, near the rise of the River Bann, where it issues as a considerable stream from the mountain side, at an elevation of 1,467 feet above the level of the sea. The superficial extent was 215 statute acres, its capacity nearly 225,000,000 cubic feet of water, and the extent of drainage 1,802 acres, or not much more than half the drainage of Lough Island Reavy, and consequently, not equal to that reservoir, in its available resources.

The Corbet Lough, or auxiliary, reservoir was to receive its principal supply from the flood-waters of the River Bann, being situated immediately above the principal manufacturing and bleaching establishments, and about 13 and 15 miles below the other reservoirs respectively, and in a favourable position for thus deriving its main supply. By the parliamentary plans it would cover an area of 74¼ acres, and contain nearly 47,000,000 cubic feet of water,

and would probably be filled four, or five times in the course of a year.

Mr. Fairbairn estimated, that the joint operation of the reservoirs, together with what the river might afford without their aid, would produce a constant and regular power of at least eight horses upon each foot of fall.

Of these works the Lough Island Reavy Reservoir has been completed. The work is laid out and the land purchased for the construction of the Corbet Lough Reservoir. The idea of making that at Deers Meadow has been abandoned, as the other two, it is anticipated, will afford more than a sufficient supply for all the wants of the river for many years to come.

It is proposed to give a detailed description of the formation of the reservoir at Lough Island Reavy (Plate 9), with some particulars and calculations of the amount of rain and supply, and a short account of the manner in which it is proposed to work the Corbet Lough Reservoir, in connection with that for impounding water at Lough Island Reavy.

The ground at Lough Island Reavy was admirably adapted for forming an immense reservoir. A shallow lake of about 92 statute acres, adjoining a tract of flat bog-land about 50 acres in extent, and only a few feet above the level of the lake, occupied the bottom of a basin in the bosom of some rugged hills lying on the flanks of the Mourne Mountains. On the north and south this basin was bounded by the steep sides of the mountains; on the east the ground rose a little above the level of the lake, forming the summit of the pass through which the mail-road from Newry to Downpatrick runs; and on the more open side, on the west, it was in great part hemmed in by two, or three of the peculiar round hills of County Down. The stone of the district consisted of granite, altered rocks, whinstone, and grauwacke slate, while scattered over the face of the country were many rocks and fragments of amygdaloidal trap.

The round hills, before alluded to, and the sides of the basin, afforded an abundance of the best materials for constructing the banks; arenaceous soil, mountain angular gravel, and argillaceous earth were to be found, while in the bottom of the basin lay a considerable quantity of dense and heavy blue clay, apparently formed by the decomposition of micaceous rocks.

The bottom of the lake itself was an immense field of fossil confervæ, many feet in thickness, very similar to those discovered by Professor Silliman in Massachusetts, North America. This interesting geological fact was first discovered by Dr. Hunter of Bryansford, and communicated by him to Dr. Drummond of Bel-

fast, by whom it was brought before the notice of the public in the 'Naturalist's Magazine.' It has since then been adverted to, in connection with a similar discovery at Blyton Car in Lincolnshire, which formed the subject of a Paper by Mr. E. W. Binney, Secretary to the Manchester Geological Society, read before the meeting of the British Association, at Birmingham. The subject has been further noticed by the late Mr. T. E. Bowman, in a Paper contained in the first volume of the 'Transactions of the Manchester Geological Society.'

This circumstance is mentioned merely for the purpose of showing how frequently engineering works may aid in forwarding the discoveries of other branches of scientific research. The confervæ consisted of an impalpable powder, and had all the appearance of finely-ground meal. Under the influence of a powerful microscope it was found to consist of beautiful parallelograms, many of them covered with striæ. They are described by naturalists as the siliceous skeletons, or coverings of minute vegetables.

It was a matter of some difficulty to determine the proper extent of the reservoir. It was desirable, that it should be made large enough to contain all the surplus water that could be gathered, so that none should run to waste, while for the sake of economy it should be no larger than was sufficient for that purpose.

Mr. Fairbairn bestowed much trouble in endeavouring to ascertain the quantity of water which it would be possible to gather from the drainage area; but the insufficiency of the data, which at that time existed, enabled him only to make a tolerable approximation. There seemed, however, to be a prospect of obtaining sufficient water to justify the reservoir being laid out as large as the circumstances of the locality would reasonably allow. This was accordingly done. It was determined to raise the water to a height of 35 feet above the summer-level of the lake, and to draw off as much below the level as would be found useful, or practicable.

Four embankments were required for this purpose,—two large and two smaller ones. They were all constructed in the same manner, but with a little variation in the slopes and thickness of the stone-facing, according to the exposed, or sheltered situation of the banks. The soil was removed, to the depth of 9 inches, from the base of the banks, and was reserved for re-soiling the outside slopes. Wherever peat-bog was found within the sites of the banks it was entirely removed. The whole of the substratum of the reservoir being at greater, or lesser depths, never exceeding 10 feet, or 12 feet, perfectly water-tight, either from the existence of solid rock, dense clay, or, in some cases, near the surface of the reservoir, of the

hardest and most compact mountain-gravel, (the detritus of the hills,) there was not much difficulty in securing the foot of the puddle. Trenches were sunk to a sufficient depth in the water-tight strata along the centre of each bank, and an upright puddle-wall was carried to the top of the bank. The puddle-bank was 12 feet in width at 40 feet below the top of the bank, and was diminished regularly to 8 feet at the top; it was worked in layers not exceeding 8 inches, or 9 inches in thickness in the usual manner. The banks were formed in concave layers 3 feet, or 4 feet thick, each layer being completed before another was commenced; and wherever the original ground forming the base of the bank sloped from the centre towards the sides transversely, it was cut in steps to receive the concave layers of the bank; steps were also cut at each end where the ground had considerable declivity.

In order further to secure the water-tightness of the bank, and to guard against any accidental inefficiency in the puddle, a lining of peat 3 feet in thickness was brought up on the inside of the puddle, and a layer of the same material and thickness was also laid in the direction of the slope below the face of the bank. The peat was laid in thin courses like the puddle, cut small and worked dry, being trodden together without the aid of water, or more moisture than it contained when excavated. The light and porous nature of peat when thus used, causes it to form an excellent material for stopping, or preventing leakage. The draught of a leak through a porous bank is, generally, sufficient to draw in the fibrous particles of the peat, but seldom strong enough to carry them far, so that by degrees every hole, however small, becomes choked by the successive bits of peat which are drawn in, and become like so many corks, allowing the accumulation of any adhesive, or argillaceous matter that may approach, or settle on the water-side. In this way a very open bank, if subject to no great pressure, may be made perfectly water-tight.

Above the sloping layer of peat a course of gravel, or coarse material 15 inches, or 18 inches in thickness was laid, and on this was placed the stone-pitching which formed the inner face of the bank. On the principal and two smaller embankments the pitching was 2 feet thick: the under part consisting of rough rubble-stone, and the upper part closely pitched with stone set on edge, the best for the purpose which the work produced.

On all these embankments the slopes when completed were, for 20 feet below the top of the bank, 2½ horizontal to 1 vertical on the inside, and 2 horizontal to 1 vertical on the outside. When deeper than 20 feet, the remainder of the banks sloped 3 to 1 on the

inside, and 2½ to 1 on the outside. The easterly, or No. 4 Embankment, was in a very exposed situation, and had occasionally to withstand tremendous storms from the west, which, gathered over the more open country, were here concentrated by the nearing and greater altitude of the hills, and driven with increased velocity through the narrow pass. The inside slope was consequently laid flatter than on the other embankments, being 3 to 1 all the way from the top to the bottom, and covered with very heavy stone-pitching 3 feet thick. In other respects the bank was precisely like the others.

The outside slopes and the tops of all the banks were covered with soil 9 inches thick, and were sown with rye-grass and clover seeds.

The principal, or No. 1 Embankment is about 713 yards in length, and contains about 112,020 cubic yards of material.

No. 2 Embankment is 216 yards in length, and contains 14,330 cubic yards.

No. 3 Embankment is 172 yards in length, and contains 5,050 cubic yards, and—

The Easterly, or No. 4 Embankment, is 535 yards in length, and, including the embanking for the diversions of the roads, contains about 85,300 cubic yards of material.

The total amount of material in the embankments, including earthwork, puddling, peat, stone-pitching, and soiling, is about 216,700 cubic yards; and the total length about 1,636 yards.

All the embankments are 12 feet wide at the top, and 5 feet above the top water-level.

For the purpose of discharging the water, a culvert is constructed under the principal embankment (Plate 10), divided at the centre by a mass of solid masonry, through which three pipes 18 inches in diameter are passed. The mouth of one pipe is stopped at the first joint, being inserted merely as a precaution in case of damage to the other two which are used for discharging the water. The inner half of this culvert is open to the reservoir, and is therefore always filled with water; the outer part contains the two discharge-pipes which are continued to the outside of the bank, the valves being placed at the outer end, and enclosed within a vault, or chamber. All the stonework connected with this part of the work is of granite; the side-walls of the culverts are formed in two courses, the lower one 21 inches, and the upper one 18 inches thick; the inverted arch is 14 inches at the centre, and the arch 15 inches, made up of ashlar, square-jointed through, and truly bedded to the different radii; the division at the centre is 5 feet thick, built of squared ashlar. The foundations are deep enough to enable the

pipes to draw 3 feet of water from the original lake, and to allow the whole of the masonry of the culverts to be below the surface of the original ground, which there consisted of very hard, compact, and retentive gravel.

The inner culvert is laid upon a bed of concrete 18 inches thick, and should have been surrounded by puddle, or rather pounded clay 2 feet thick, the excavation being made exactly large enough to contain the masonry and the puddle. This part of the plan, however, was altered without the Author's concurrence, and he remained unaware of the alteration, until the bank had been raised to a considerable height. The superintendent, deeming the masonry too weak without the backing which is customarily added, most injudiciously placed a quantity of rubble-backing behind the side-walls, and then surrounded the whole with the clay, which should have been in immediate contact with the masonry. Little harm would have followed, had he not continued this rubble-work past the solid dividing masonry, and through the centre puddle to the outside of the bank. This constituted a rubble-drain entirely through the bank from the inside of the reservoir, and with a pressure of about 12 feet of water, the mortar in some of the joints gave way, and considerable leakage ensued.

The mortar was prepared from the mountain limestone from the Isle of Man, according to the directions given for making hydraulic mortar from rich limes, by M. Vicat, whose work on cements, translated by Captain Smith, had just then been published.

No hydraulic lime could be procured in the neighbourhood, and being unwilling to incur the expense of Roman cement for the whole of the masonry, samples of the various limes, both burned and unburned, which could be procured in the neighbourhood of Lough Island Reavy, consisting of Manx lime, Carlingford lime, both from the mountain, or secondary limestone, and the Moira lime, a white, or chalk limestone, together with the various pure and arenaceous clays which were found at the place, were brought to England in the autumn of 1837, about which time the works were commenced, and with these materials M. Vicat's experiments were carefully repeated. So close a similarity was found in the results, that, after six, or seven months' trial, it was determined to employ mortar composed of rich lime and burned clay, in the proportions which were found to harden best under water. The Manx, or mountain lime had produced more satisfactory results than the chalk lime, and was therefore used. The lime was carefully slaked to powder, from which the unslaked, or unburned lumps were separated by screening. The clay was broken into small lumps and burned

with peat in the open air to a red heat, after which it was ground, and all stony particles larger than sand were separated by screening.

The lime and clay were both measured in powder, the proportions being 2½ of clay to 1 of lime, and were intimately mixed with water, and ground in an edge-stone mortar-mill; no more water being used than was sufficient to bring it to a consistency about as stiff as potters' clay. The mortar thus made was used immediately. The backing mortar had about 1 measure of sand added; the grout from 1 to 2 measures of sand, and was used rather thick than thin.

The concrete was composed of 1 part of lime, 2½ of calcined clay, and about 3 of sharp gravel.

The culvert was set with mortar, composed as above, in the summer of 1838, and in the spring of 1839, a careful examination was made of every joint, the mortar having been almost constantly under water during the meantime, though it had never had more than 4 feet, or 5 feet of pressure. It was found to be, apparently, perfectly set and hard, resisting all pressure with the finger, or a piece of stick, and yielding nearly a dry powder, of a beautiful olive-brown colour, when scraped with a knife.

Every confidence, therefore, was placed in the success of the experiment and in the security of the work, particularly as at that time the existence of the rubble-backing was not imagined. During the following summer the reservoir was partially filled, and when about 12 feet deep, several leaks made their appearance in the outer culvert, breaking out principally at the upper end, close to the dividing masonry. The leak continuing to increase, the water was drawn off; and in November an opportunity was afforded for investigating the cause of the leakage. All the mortar in the inner culvert, which six, or eight months before had been perfectly hard, was found to be as soft as if newly made, except in the invert and just under the crown of the arch. From many joints, particularly at the lower end, the mortar was entirely gone, and communications existed on all sides into the open rubble-work behind. From the circumstance of the mortar still remaining comparatively hard at the crown of the arch, where the puddle came into immediate contact with the back of the masonry, thus preventing the escape of the water, it is possible, that had the original instructions been correctly followed, and the whole culvert been surrounded with pounded clay, no leakage would have occurred; but the impression created was, that with increased pressure the mortar would have been entirely destroyed.

This experiment, therefore, seems to show, that mortar made from rich lime and calcined clay, as recommended by M. Vicat, may

set and harden under water where there is little, or no pressure; but that it is not able to resist the penetrating weight of a great depth of water.

The mode adopted to remedy the defect, and to prevent further leakage, was simple and perfectly efficacious. The mortar was picked out of every joint as far as a thin picker, or scraper, made for the purpose, could be made to penetrate, the joints were then caulked with oakum driven in with a tool and heavy mallet, as hard as possible, to within about 2 inches, or 3 inches of the face, the remaining space being filled with Roman cement. The backing which had been brought close up to the back of the breast-wall of the fore-bay, was taken out for a short distance, and pounded clay was substituted so as to bring the puddle, surrounding the backing, round the ends to the back of the culvert, and to the concrete of the foundation, thus preventing any escape of the water by the ends of the backing.

The reservoir has since then been filled, having nearly 30 feet in depth above the pipes in the following spring (1840); and although when it was quite full a trifling escape again appeared in the culvert, it was so small, and presented no appearance of increase, that no uneasiness was created. It probably arose from some joints being missed in the former repairs, and the defect will be corrected, whenever the reservoir is low enough to allow of its being emptied for the purpose of examination. No other defect is apparent in the entire work, and not a drop of water has escaped through the embankments.*

The masonry of the fore-bay and of the discharging-chamber is built of good flat-bedded, or squared granite, in a substantial manner, according to the dimensions given in Plate 10.

---

* Since the above was written the reservoir was emptied, and an examination was made in November, 1841. When previously examined, the sides and arch were alone repaired, the bottom, which was placed on concrete, not appearing to require it, as the mortar exhibited no appearance of giving way. At the second examination, however, the mortar from this part of the work had entirely disappeared, the stones being as bare as if they had been set dry, which at once accounted for the escape of the water. The parts previously repaired were as perfect as possible, the cement in the joints having become nearly as hard as the stone. The open joints were thoroughly filled up with the best cement, and everything else done which was considered desirable, and the water was again let on in the beginning of December. From that time to May, 1842, the water was allowed continually to increase in depth to about 30 feet. Observations were constantly made, and the last report of the man appointed to the charge, was, in the expressive style of his country, "if it were ink, I would not find as much escaping as would enable me to sign my name."

The front of the discharging-chamber, or valve-house is smooth, chisel-dressed, with square sinkings at the horizontal joints, and is built in a bold Egyptian style; the wing-walls are rock-faced with chamfered horizontal edges, built in courses to correspond with those of the centre, or valve-house, and covered with a chisel-dressed coping 6 inches thick. A bridge is thrown over the water-course, from the pipes in front of the valve-house, to form a platform for the entrance; and under this bridge the water is discharged from the mouth of the pipes, into a pool of water, at all times 18 inches deep, and, during the period of an ordinary discharge, having a depth of about 3 feet. By being thus discharged into water, the violence of the force with which the water issues from the pipe is broken, and much wear and tear is avoided. For some distance, (about 40 yards,) from the mouth of the pipes, the water-course is protected by squared stone-pitching 12 inches deep, set cross-ways to the stream and grouted, with side walls 2 feet thick of flat-bedded wall-stone set in mortar.

The discharge-pipes were 18 inches in diameter, cast 1 inch thick, with flange-joints properly faced and ground water-tight: they are bell-mouthed at each end. The valves (Plate 11) were constructed of sufficient strength to bear a considerably greater water-pressure than they would be required to do, with brass slides and seating, properly faced and ground water-tight. The box, or case of each valve was cast 1 inch thick, with a frame fixed on the cover to receive the fly-wheel rim, adapted to raise and lower the valve. The spindle, or lifting rod passes through a stuffing-box, and raises the valve by means of a brass-bush, working upon a square-threaded screw. These valves work perfectly easy under the greatest pressure they have to bear.

A waste weir, 60 feet in length (Plate 11), for discharging the surplus water when the reservoir is full, is constructed on the outside of the principal embankment, where the feeder from the River Muddock enters the reservoir. The excavations for the foundations were deep enough to allow the whole weir, when completed, to be below the surface of the original ground. The weir is formed first in steps, dropping 8 inches at each step, and then descending gradually from the step, at an inclination of about 1 in 5, till it communicates with the water-way from the discharge-pipes. Each step forms a segment of a circle, and they are so arranged, that the water from the last is discharged directly in the line of the lower part of the weir, although the commencement of the weir is at a considerable angle. The steps are formed of stones 3 feet in depth, the first row being 12 inches, and the others 9 inches in thickness, set side by side in a

trench cut out of the solid ground with joints dressed to the radii. A flat course of stones 12 inches thick, the first course 2 feet, and the others 15 inches in breadth, is laid in front of and 8 inches below each row of stones, forming the steps above described, with joints wrought to the respective radii. The whole of this part of the work was set flush in hydraulic mortar. The remaining spans between step and step are filled up with hammer-squared stones 12 inches deep and grouted; and the remainder of the waste water-course, to its junction with the water-way from the pipes, is pitched with similar stones, having at every 15 feet in distance a row of stones from 2 feet 6 inches to 3 feet in depth, 9 inches thick, and not less than 3 feet long, extending across the water-course from side-wall to side-wall. The whole of the pitching was set on a course of small rubble-stone and well grouted. The side-walls are 2 feet thick, built of good flat-bedded hammer-dressed wall-stone, the top course forming a coping 12 inches thick, square-jointed through, neatly dressed on the top, and the whole set flush in good mortar.

On the back of the weir, or side next the reservoir, is laid a puddle-lining 18 inches thick, tied into the puddle of the embankment at one end, and rising at the other in the feeder from the Muddock, to above the top-water level of the reservoir, so as to prevent any leakage through the porous ground: the whole of this puddle is covered with heavy squared-pitching 9 inches deep.

A bridge of three arches, each 15 feet span, is built at the end of the principal embankment across the feeder from the River Muddock, both for the purpose of admitting the water from that feeder into the reservoir, and for allowing ample space for the surplus water from the reservoir to reach the waste weir, and at the same time to connect the embankment with the adjacent ground.

The foundations of the bridge are laid on the puddle upon the largest flat-bedded stones that could be procured, and the whole work is rock-faced except the coping of the bridge and the coping and top-stones of the cut-waters, which are chisel-dressed.

The pitching from the back of the waste weir extends under the bridge, and 12 feet beyond it, on the reservoir side, where it abuts against a rock, from which a channel is sunk below the original surface of the ground, to prevent the water from the feeder washing over and injuring the embankment in times of flood, when the reservoir is low.

The mortar used was compounded in the same manner as that for the discharge-culverts, and having little pressure to sustain, it seems to have answered well.

The ground between the weir, or waste water-course, and the foot of the outside slope of the embankment, from the bridge to the discharge-vault, or valve-house, was neatly sloped down and sown with rye-grass and clover-seeds; with a gravel walk, 4 feet 6 inches wide, leading from the bridge to the valve-house.

The reservoir having little natural drainage from the hills which immediately bounded it, it was necessary to divert several streams, and construct artificial feeders, to bring to it the requisite supply of water. Of these feeders, the most important is that from the River Muddock (Plate 9); being, in fact, a diversion of the entire river. The mills lying between the point of diversion and the point at which the water is returned to the river from the reservoir, have either been purchased by the Company, or such an arrangement has been made as gives them the control of the water, subject to the constant supply of so much as is required to work the smaller mills which lie upon the lesser stream from the original lake.

This feeder is 1 mile 550 yards in length, 4 feet 6 inches deep, 22 feet 6 inches wide at the top, and 9 feet at the bottom. By proper waste-weirs and stop-gates at the upper end, the depth of water can be regulated so as never to exceed 3 feet, or the whole stream can be turned down the old river-course when the reservoir is full. The feeder is carried along the sloping face of the hill, the excavated material forming an embankment on the lower side. A considerable portion of it is lined with puddle, the ground generally being very porous; the banks are neatly trimmed, covered with soil, and sown with hay-seeds. Across the feeder are twelve, or fourteen road and occupation-bridges, of various sizes.

There is a fall in the whole length of about 10 feet, more, perhaps, than was required; but this inclination most conveniently suited the circumstances of the ground. The floods are sometimes excessively heavy, but the bottom and inside slopes of the feeder are found to stand the wear and tear without injury.

The Moneyscalp feeder was constructed to convey the surplus waters of the Moneyscalp stream to the reservoir. As the water, required to aid in the working of the mills below, amounts to a very small quantity, nearly the whole of this stream, which is occasionally swelled into a considerable brook, is taken into the reservoir. Proper gauge-weirs are fixed at the point of diversion, to secure to the mills below their requisite quantity, before any can flow to the reservoir.

The feeder is 1,060 yards long, 4 yards wide, and 1 yard deep, and is lined with puddle, where requisite, to make it perfectly retentive.

The Slievenalargy stream, a mere mountain torrent, is conveyed to the reservoir by a drain of sufficient capacity.

The water which is collected by these three feeders, together with the natural drainage into the lake, forms the entire supply to the reservoir. The area of the surface drained from is about 3,300 statute acres.

The old drain, or stream, from the lake to the river, about a mile in length, has been made 5 yards wide, to allow sufficient space for the water discharged from the reservoir to flow to the river.

About two miles of county-roads have been diverted, the new ones being constructed at the expense of the Company, to the satisfaction of the county-road surveyor. They present a great improvement upon the hilly ones which previously existed.

The total engineering cost of the work, exclusive of salaries and professional charges, has been as follows:—

	£.	s.	d.
Reservoir, embankments, and works .	12,300	0	0
Discharge-pipes and valves . . .	291	13	0
Feeders with their bridges, &c., including that from the reservoir to the river .	1,500	0	0
Diversion of county-roads . . .	800	0	0
Total .	£14,891	13	0

The land, with compensation to the tenants for damage, and the value of some chief rents, payable by the Company, has cost about £6,000.

The whole of the work, with the exception of the discharge-pipes and valves, and a few unimportant details, was let to Mr. Dargan, now of Belfast, and has been executed by him in the most substantial and creditable manner. The work was commenced late in the autumn of 1837, was suspended during the winter of 1838–9, and was finally examined and approved in February 1840, the principal parts having been completed some time previously.

The pipes and valves were constructed in a satisfactory manner by Messrs. Coates and Young, at the Lagan Foundry, Belfast.

Mr. John Geekie was the superintendent, and to his zealous watchfulness much of the success of the work is to be ascribed.

Immediately after the Act was obtained the Author had the honour of being appointed Engineer to the Company, with the liberty and advantage of consulting Mr. Fairbairn. One of his first objects was to obtain a correct account of the amount of rain

and available supply, a subject of great importance to the Company, and to which Mr. Fairbairn particularly alluded in his Parliamentary Report. It is to be regretted that all efforts, in a great measure, proved unavailing. The Company could never be impressed with the conviction, that such observations could be of use to them, and would not, consequently, incur any expense. All that was done was, therefore, on the Engineer's own responsibility. Two rain-gauges were sent over and erected: one at Lough Island Reavy, near the lake, about 400 feet above the level of the sea; and the other at Deers Meadow, on the summit of a mountain, about 1,400 feet above the sea, being about half-way in height between the basin of Deers Meadow and the average summit of the surrounding eminences. Gauges were also fixed in the River Bann, at the outlet from the Deers Mountain basin, and in the Moneyscalp stream at Lough Island Reavy, for the purpose of measuring the quantity of water flowing out, the extent of ground from which it was gathered being accurately ascertained.

No persons could be found to follow out the instructions correctly; and, as no reliance, therefore, could be placed upon the river-gauge observations, they were, after some time, entirely abandoned. The rain-gauges were rather more fortunate, and the observations were continued for about two years. They were put down on October 14, 1837, and from the returns the following monthly amounts to October 14, 1838, are extracted:—

		At Lough Island Reavy.	On Spelga Mountain.
1837	Oct. 14 to 31	3¼ inches	3¼ inches
,,	Nov. ,,	4¾ ,,	3¾ ,,
,,	Dec. ,,	10½ ,,	9¼ ,,
1838	Jan. ,,	..	5½ ,,
,,	Feb. ,,	..	10¾ ,,
,,	March ,,	..	12 ,,
,,	April ,,	..	4 ,,
,,	May ,,	5¾ ,,	4½ ,,
,,	June ,,	3¾ ,,	about 6 ,,
,,	July ,,	4½ ,,	about 5 ,,
,,	Aug. ,,	5 ,,	3¾ ,,
,,	Sept. ,,	1 ,,	5 ,,
,,	Oct. to 14 about	2 ,,	1¼ ,,
		40½	74 inches.
If the 4 months wanting be taken the same as on Spelga		32¼	
		72¾ inches.	

The gauge at Lough Island Reavy was destroyed on the 30th

December 1837, and was repaired and put down again on the 1st May, 1838; there are, therefore, no returns for the intervening period.

The rain which fell at Manchester during the year 1838 was only about five-sixths of the average quantity; and, as there is not much difference in the seasons, between the east coast of Ireland and the west coast of England, it will not be overrating the depth of rain which falls on the Mourne Mountains, to take it at 72 inches, or 6 feet per annum. Of the proportion lost by absorption and evaporation, unfortunately no accurate results have been obtained. Mr. Thom found that, at the Greenock Reservoirs, in an excessively dry season (the year 1826) the available rain to the total fall was as 239 to 454, little more than one-half; and in a wet season (the year 1828), as 744 to 1,088, rather more than two-thirds. The same proportions would yield, at the Bann Reservoirs, about 3 feet and 4 feet respectively. The quantity capable of being collected at Lough Island Reavy, from its 3,300 acres of drainage, would be, at 3 feet per annum, 431,244,000 cubic feet; and, at 4 feet per annum, 547,992,000 cubic feet. As the capacity of the reservoir is about 290,000,000 cubic feet, the first quantity would fill it once and a half, and the second twice in the course of the year. The truth of this calculation was pretty well corroborated during the last winter (1840–41), as the reservoir filled, from being empty, in half a year, though the season was unusually dry.*

Observations upon the River Bann, and information received, have led to the conclusion, that about four months in the year may be considered as the measure of the dry seasons, or the time during which it will be necessary to discharge from the reservoir. Supposing the reservoir to be once and a half filled only, or 435,000,000 cubic feet of water to be impounded in the course of a year, it will be able to afford, during the dry periods, a constant average stream, night and day, equal to 42 cubic feet, or 3½ H.P. per foot of fall. The circumstances of the river require that the discharge should be nearly constant.

There are very few mills on the river, and none of much present importance, between the junction of the River Muddock and the outlet from Corbet Lough. Below this point the river is closely occupied with important establishments. The situation of Corbet Lough was, therefore, well suited to form an auxiliary reservoir, to

* This was further corroborated, since the Paper was written, by the reservoir filling 30 feet in depth from the beginning of December, 1841, to the end of April, 1842.

impound the night water from Lough Island Reavy, and to catch the river floods.

A few calculations will show the importance of such a reservoir. The average power of the river at this point, without the assistance of the Lough Island Reavy Reservoir, during the summer months, is about 2 H.P. per foot of fall, and for about four months in the year it will not exceed this quantity. With the supply from Lough Island Reavy, as above assumed, the constant power will be 5½ H.P. per foot. As the river will always have this quantity in it, and the dams above the various weirs, therefore, be full, it would be a waste of water, when the mills cease working, to allow it to run by unused during the night, if a convenient place for storing it could be found. To save this water it will be turned into the Corbet Lough Reservoir, when it is completed, and be discharged again the next morning, when the working of the mills puts the river again in motion, thereby doubling the power of the river for the twelve working hours of the day, increasing it from 5½ H.P. to 11 H.P. per foot of fall. Allowing sufficient for waste, by leakage at the weirs, or high evaporation during the night, the available daily power would probably be about 9½ H.P., or 10 H.P.

In addition to this, the summer floods, from calculation founded upon what appears to be very accurate information, may be expected to fill the reservoir something more than three times during the season, and the natural drainage into the lake will fill it at least once again, during the same period, from casual floods. To this quantity, obtained during the dry seasons of the year, must be added the reservoir once filled in wet seasons, and then remaining full until the river again requires its assistance; making five reservoirs full in a year, equal, at the height to which it is intended to impound, to 110,000,000 cubic feet, available to the river, exclusive of the water above calculated, saved during the night. Taking the period of discharge again at four months, and twelve hours a-day, from this reservoir, this quantity will add upwards of 2 H.P. to every foot of fall below its outlet, making the entire power of the river about 12 H.P. per foot. But as the remaining eight months may not always be equal to this power, without drawing from the reservoirs, the constant quantity, at all times to be relied upon, probably may not exceed 10 H.P., or 11 H.P. per foot of fall.

Therefore, when the whole of the works contemplated are completed, the regular power of the river will be as follows:—On the Muddock, to its junction with the River Bann, a fall of 124 feet, it will vary with the discharge from Lough Island Reavy. From the junction with the Muddock to Corbet, a fall of 44½ feet, the Bann

will always, night and day, be equal to about 5 H.P. per foot, and below Corbet Lough, to the last mill on the river, a fall of 168 feet, to 10 H.P., or 11 H.P. per foot of fall.

Taking into account the cost of moving power to be obtained by any other means in the North of Ireland, and the probability that the whole power of the River Bann will, ere long, be usefully and profitably employed, few works of a public nature have been attended with more satisfactory results, or have been followed by such a vast increase in the value of property. The Author cannot help remarking, that the natural resources of Ireland require only to be developed and properly applied, to raise that country to a high standing amongst manufacturing nations; and it is hoped, that the success of the Bann Reservoirs will lead to the execution of many other undertakings calculated to improve the condition of the people.

Corbet Lough Reservoir.

The Corbet Lough Reservoir (Plate 12) was designed as an auxiliary, or assistant reservoir, to receive the flood waters of the lower part of the river, and to retain the night water, to be discharged again during the day, immediately above the more extensive mills upon the river, which extend for about thirteen miles below this point. About five miles above the town of Banbridge, on a level with the river, there was a small and shallow lake, called Corbet Lough, about 31 English acres in extent; this lake was about a mile and a third below a mill-fall on the river, between 6 feet and 7 feet in height, in the occupation of Mr. Ervine, the surface of the water in the lake being on a level with that of the river below this fall. It was proposed to construct a water-course of considerable dimensions, from the river, immediately above Mr. Ervine's weir, to the lake;—to throw an embankment across the narrow outlet of the lake, so as to impound the water to the greatest height to which the floods rise over the weir; the water being admitted to the reservoir by self-acting flood-gates, which should close when the lowering of the river created a current in the contrary direction;—and generally, to work the reservoir, so as to prevent any waste of the water impounded at Lough Island Reavy, and to regulate and economise, as perfectly as circumstances would permit, the water power of the river, below the outlet from Corbet Lough. The extent of country naturally draining into Corbet Lough being small, and the occurrence of floods in the river being uncertain, there was little advantage to be gained from the construction of this reservoir, until after the completion of the very spacious one at

Lough Island Reavy; when it became of great value to the large establishments near Banbridge, for whose benefit Lough Island Reavy was chiefly constructed, and the ordinary discharge from which was more than sufficient for the working of the small mills above Corbet Lough.

It appeared, from careful observation, that about four months in the year might be considered as the average of the dry seasons, or the time during which it would be necessary to draw from the reservoir at Lough Island Reavy, for the accommodation of the mills near Banbridge. That reservoir was calculated to afford a constant average stream, night and day, for four months, equal to 42 cubic feet per second, or 3½ H.P. to each foot of fall. The great distance of the reservoir from the mills using the water, and the great length of river occupied by the latter, required, in order to insure to each mill its fair share of the benefit to be derived, that the discharge from Lough Island Reavy should be nearly continuous. Measurements of the river showed, that the average natural, or unaided stream at Corbet Lough, during the summer months, was about 25 cubic feet per second, or 2 H.P. per foot of fall, and it might be taken, as not exceeding that quantity for four months in the course of the year. With the assistance of the water discharged from Lough Island Reavy, the power of the river during these periods of drought, would be brought up to 5½ H.P. for each foot of fall, with a constant flow, night and day.

The first use of the Corbet Lough Reservoir was to retain the water which passed down during the night, when it was of little service to the mills, and to discharge it again during the working hours of the day.

The whole river between Corbet Lough and the lowest mill, at Moyallan, near Lough Neagh, consists of a series of dams, and it was evident, that if these dams were full at night, when the mill ceased working, they would, with some small allowance for leakage, be in the same state the next morning, although no additional water was allowed to flow down the river. If, therefore, the river were turned into Corbet Lough, when the mills stopped at night, and turned out again in the morning, the power of the river during working hours would be doubled, being raised from 5½ H.P. to 11 H.P. per foot of fall. But in order to allow for leakage at the weirs, and the partial use of the water during the night, it was considered, that about 1½ H.P. ought to be allowed to flow down during that time; thus leaving the power of the river in the day equal to 9½ H.P. per foot.

The next important advantage to be secured by the construction

of the Corbet Lough Reservoir, was the opportunity afforded of impounding every casual flood which might occur during the summer months, or at other seasons. The reservoir, when filled, was capable of containing about 22,000,000 cubic feet of water.

It appeared, from the best information which could be obtained, that the reservoir might generally be expected to fill from the river floods, rather more than three times during the summer. The country naturally draining into it, would fill it at least once more, within the same time, and to this quantity, obtained during the dry seasons of the year, must be added the full state of the reservoir during the wet season. Thus it would be completely filled five times, and, consequently, yield 110,000,000 cubic feet per annum, in addition to the water saved during the night. Taking the period of discharge at four months, there would be added, during twelve hours per day, from the water thus stored, rather more than 2 H.P. per foot of fall, below the outlet of the reservoir, to the lowest mill on the river, making the entire power upwards of 11½ H.P. per foot. But as, during the remaining eight months, the river might not always be equal to this power, without drawing from the reservoir, and as it would, in such cases, be necessary to lengthen the period of discharge, and, consequently, to diminish the quantity, it was assumed, that the constant quantity at all times to be relied upon, would be 10 H.P. per foot.

The effect upon the regular power of the whole river may be thus stated:—on the River Muddock, below Lough Island Reavy Reservoir, to the junction with the Bann, a fall of 124 feet, the volume of the stream would vary with the discharge from Lough Island Reavy:—from the junction of the Muddock and the Bann to Corbet Lough, 44½ feet of fall, the power of the river would always, night and day, be equal to about 5 H.P. per foot;—and below Corbet Lough to the last mill on the river, a fall of 168 feet, to 10 H.P. per foot during the day, and about 2 H.P. at night.

These calculations clearly show the important advantages to be gained, for manufacturing purposes, by the construction of auxiliary reservoirs, in suitable positions, on streams which have the benefit of possessing large impounding reservoirs near their sources. The construction of the two reservoirs at Lough Island Reavy and at Corbet Lough has increased five-fold the value of the mill power on the River Bann, and this additional power has been obtained at a cost of about thirty shillings per H.P. per annum.

In designing and executing the works for the Corbet Lough reservoir, the closest economy, consistent with the efficiency and durability of the work, was rigidly kept in view. The masonry

principally consists of rubble-work, no ashlar being introduced, except where it was absolutely necessary. The rubble is composed of the hard basaltic rock, so commonly found over the north of Ireland, and the ashlar is of granite, chiefly obtained from the neighbourhood of Newry. The stop-gates, flood-gates and sluices, are constructed of timber, and can be easily repaired, the working gear, however, being of a very permanent character.

The discharging apparatus of the reservoir is entirely constructed of iron. It consists of three sluices, each 5 feet long and 1 foot deep, placed in a breastwork of masonry.

The water-course, to convey the water of the river to the reservoir, is 2,409 yards in length, with a fall of 1 foot from end to end, and is, for the greater part, cut out of the solid ground. It is 16 feet wide at the bottom, 6 feet deep at the upper end, and 7 feet at the lower end. The slopes of each side are at an inclination of 4 horizontal to 3 vertical. The width of the channel at the top of the bank is 32 feet at the upper end, and 34 feet 8 inches at the lower end; at one part, it is carried through the ridge of a hill by some deep cutting, and there it measures 21 feet in width. The bottom of the water-course, at its commencement, is 18 inches below the level of Mr. Ervine's weir, and the water is withdrawn from the river by a side-weir, about 90 feet in length, the top of which is level with Mr. Ervine's weir. In the latter, there are two small sluices for passing the water into the water-course, when it is not required to be used.

The weir (Plate 14) consists of a top course of ashlar, 18 inches broad and 2 feet thick, set upon a foundation of good rubble-work, sunk to a sufficient depth below the river. It forms a segment of a circle of which the radius is 90 feet. The front and back are protected by gravel puddle, pitched over with squared stones. The abutments and water wings are of rubble-work.

Immediately below the weir, and as soon as the water-course is contracted to its proper width, stop-gates are placed, for regulating the quantity to flow down the water-course, and for shutting it off when the reservoir is full. These gates consist of five openings, each 4 feet square. The framing is composed of red deal, and the shuttles are of oak plank, 3 inches thick; the whole is securely fastened with mortice and tenon joints, and wrought-iron bolts. The shuttles are raised and lowered by a winding apparatus, each consisting of a rack and pinion, worked by a cog-wheel and worm. In order to preserve it from injury, the whole apparatus is enclosed in an iron casing. The timber framework is securely built into rubble abutments and foundation.

The water-course is crossed by four county-road bridges, three of which are at very acute angles, and by a number of occupation-bridges. In the skew-bridges the impost, or springing course, is of ashlar: the arches are of hammer-dressed coursed-work, and the remainder of rubble-work. All the other bridges are of rubble-work, except the arches, which are of hammer-dressed coursed-work. In some cases, where the ground was tender, it was found necessary to pitch the slopes of the water-course, and to puddle some parts to make it water-tight.

The embankment of the reservoir is raised to a height of 12 feet above the summer level of the old lake, and the works are so arranged, that a flood of 3 feet 6 inches over Mr. Ervine's weir may be impounded. This embankment is 12 feet wide at the top, with slopes on each side, of 2 horizontal to 1 vertical. A puddle trench along the centre of the bank was sunk into retentive ground: the puddle was 8 feet thick at the surface of the ground, and 6 feet at the top of the bank. The inner part of the bank was composed of clay, or other adhesive material, laid in layers 12 inches in thickness, and pounded: the outer part was placed in layers 3 feet in thickness; all the layers sloping towards the centre of the bank, the inner slope being pitched over with rubble-stone, 18 inches in depth.

The water is discharged by three sluices (Plate 15), each 5 feet long and 1 foot deep, placed in a breast-wall of solid masonry, made up of ashlar set in cement, as far as is necessary to turn the water. The remainder of the masonry is of good block and course-work, except the coping and the stones to which the winding apparatus is fixed, which are of ashlar. The spaces between the wing-walls, both of the fore-bay and the tail-bay, are pitched with squared stones placed on a foundation of gravel puddle, composed of gravel and clay, well pounded together. On the water side, the wing-walls are puddled behind, the whole being made water-tight; and grooves for the stop-planks are left in the face, so that the water may be stopped off, and the discharging sluices be examined, or repaired. A wood cill, and a vertical pile, to aid in resisting the pressure, are prepared for the stop-planks.

The discharging apparatus consists of three cast-iron shuttles, working in cast-iron frames, properly faced, and ground water-tight, with lifting rods, furnished with brass bushes, to work on square-cut screws, fitted in frames on the top of the wall; and proper keys are provided for working the screws.

The water from the river is admitted into the reservoir by self-acting flood-gates (Plate 16), which, turning on a vertical shaft,

open and shut by the unequal pressure of water on the one side, or the other. These flood-gates, and the framework in which they are fixed, are made of red deal. The framework is built into abutments of block and course-work, and bolted to a foundation course of ashlar. The gates are firmly united with mortice and tenon joints, and are strengthened by cast-iron shoes, and wrought-iron stays and straps. Each gate works on its centre, by a chilled-iron cup, resting on a chilled-iron pivot, 4 inches in diameter, turned to fit each other, so as to allow the gate to swing freely. The upper part of the gate is furnished with an upright iron shaft, 4 inches in diameter, working in an iron collar bolted to the framing. Piles are driven down in proper positions, to prevent the gates from swinging too far back. The water-course is pitched with squared stones, placed on puddle, for some distance on both sides of the flood-gates. The top of the flood-gates answers as the waste-weir of the reservoir when full, and for 9 feet, or 10 feet, outside the flood-gates, the pitching is laid on flags, and set in mortar, in order to protect it from being torn up by the fall of the water over the gates.

At the end of the water-course, adjoining the reservoir, and near the self-acting flood-gates, is constructed a waste-weir (Plate 13), 30 feet in length, with a channel to conduct the water from the discharge-sluices to the water-course. The top of the waste-weir is 6 inches below the top of the self-acting flood-gates, and it serves both for the discharge of the waste water from the reservoir and for carrying off any surplus water which may pass down the water-course. The waste-weir is a segment of a circle, formed to a radius of 32 feet 8 inches. The top course is of ashlar, 2 feet wide, and 12 inches thick; and the remainder of the masonry is of block and course-work, except the apron, which is formed of squared pitching 12 inches deep, with a cross row of flags on edge, at intervals of 5 feet, or 6 feet. The channel is paved to its junction with that from the discharge-sluices. A sluice 2 feet square, with a suitable shuttle, frame, and winding apparatus, is placed in the weir, for the purpose of drawing the water out of the water-course. The channel leading to the sluice is sunk and paved in such a manner, as to cause the current to sweep past the flood-gates, and to convey away any sand, or sediment, which may have there accumulated.

A water-course, or channel, is formed from the discharge-sluices to the river, for the purpose of conveying the water from the reservoir. It is sunk to a depth of 3 feet below the ordinary summer level of the river, and is protected to its junction with the channel of the waste-weir last described, by pitching, brought up into curved side walls with a heavy coping. The water-course is 18 feet wide,

and is crossed by a county-road bridge, built in the same manner as those already described: the road was slightly diverted, in order to make the bridge square.

The whole work, which was completed in the summer of 1847, has been executed under the superintendence of Mr. W. Loftie Stoney, at the cost of £3,300.

The Paper is illustrated by a series of diagrams, from which Plates 9 to 16 are compiled.

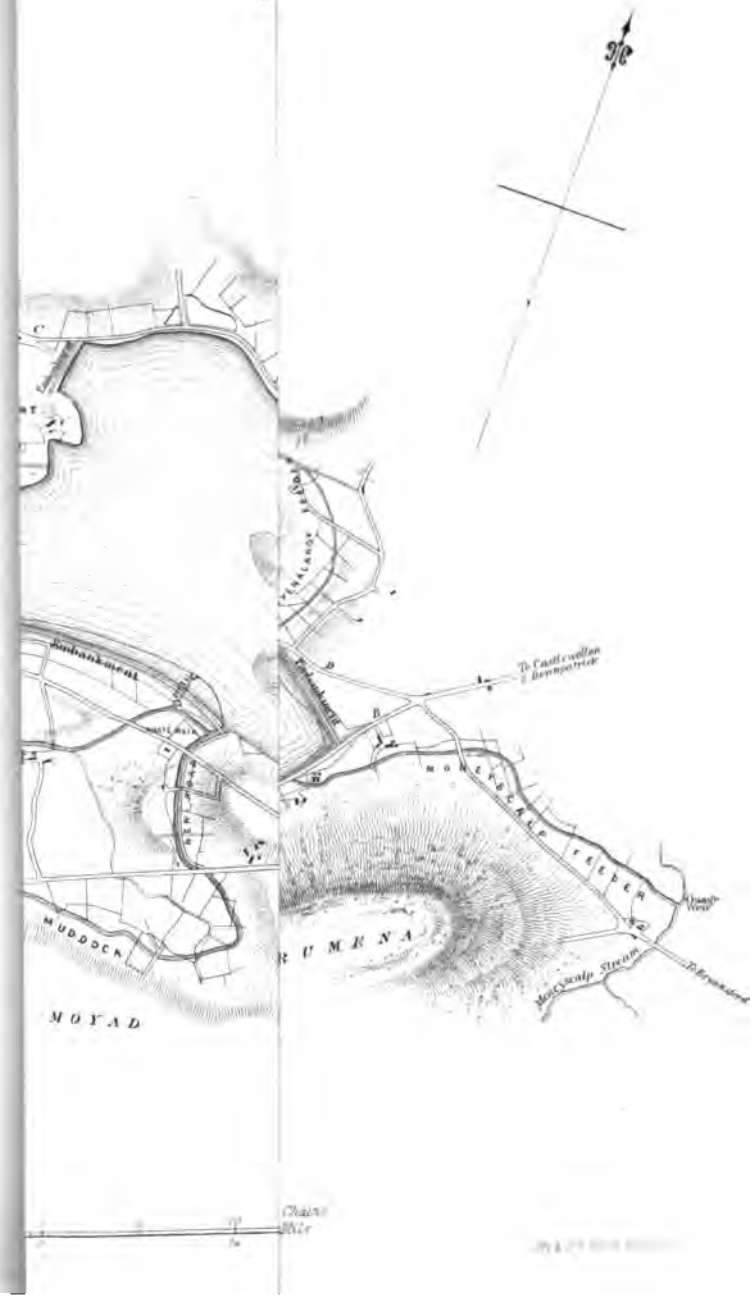
Mr. BATEMAN recapitulated the general features of the Bann Reservoirs, and detailed the advantages that had resulted to the mill-owners, and the consequent increase of value of the property in the district, from the system of impounding the surplus water, to be used at times when, but for such assistance, there would be a scarcity. He directed attention to the self-acting balance flood-gates, not on account of any novelty in the principle, but because he thought there were many positions where they might be advantageously employed. The work, generally, was very plainly, but substantially executed, and at a very small cost.

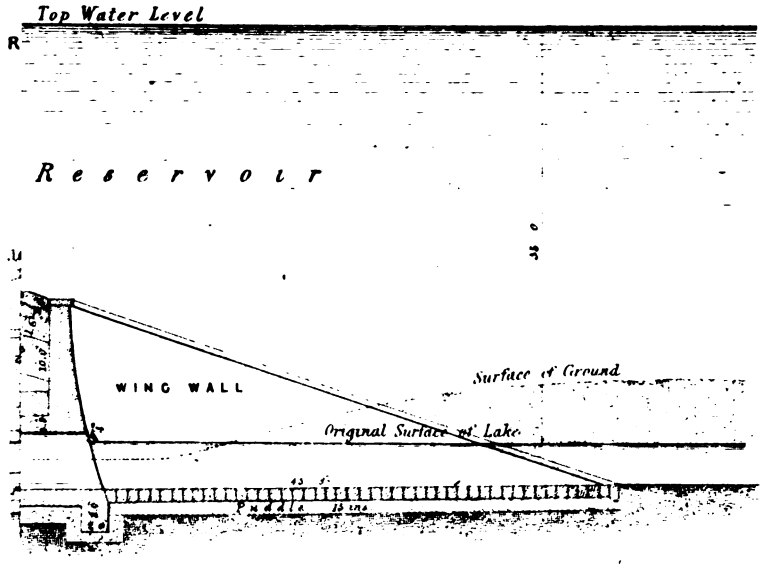
Mr. HOMERSHAM inquired, whether the Lough Island Reavy Reservoir had, at all times, been found sufficiently large to collect and yield, for regular use, the water flowing off the land in very wet seasons, and during the greatest floods; or if any large quantity of water occasionally ran to waste. It was important to ascertain the amount of storage required for a certain extent of land draining into a reservoir. The Lough Island Reavy Reservoir was equal to a storage of 82,000 cubic feet per acre; and was the largest, in relation to the drainage-ground, he had ever known.

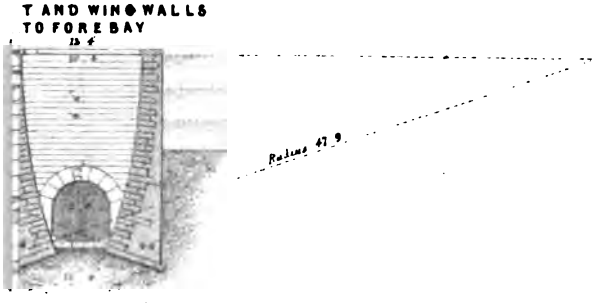
Mr. BATEMAN was not quite aware of all these circumstances; as since the completion of the works, he had not been frequently there. The capacity of the Lough Island Reavy Reservoir was 287,000,000 cubic feet, and the drainage ground was 3,300 acres. The case of this reservoir was not analogous to that of reservoirs for the supply of towns, nor to those constructed for the purpose of regulating mill-streams, occupied by mills immediately below the site of the reservoir. The mills, for the benefit of which the Lough Island Reavy Reservoir was mainly constructed, were at distances of fifteen miles to twenty miles. For six, or eight months during each year, at least, there was an abundant supply of water from other sources; and as during that period the reservoir was required to be large enough to contain all the water flowing into it,

BANN R

LO


To Castlewellan
& Newcastle
MUDDOCK
MOYAD
RUMENA
Mc Closkys Stream
Chains


Top Water Level
R
Reservoir
WING WALL
Surface of Ground
Original Surface of Lake
43'
PIPE 15 ins.


T AND WING WALLS
TO FOREBAY
Radius 47.9'

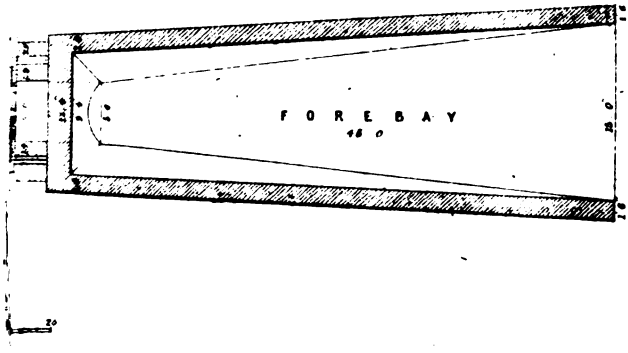
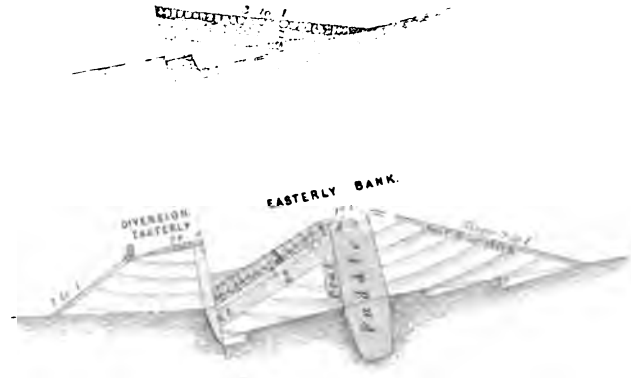

FOREBAY
48 0

PLATE II.

BANN RE

LOUG



Feet

Feet

Feet

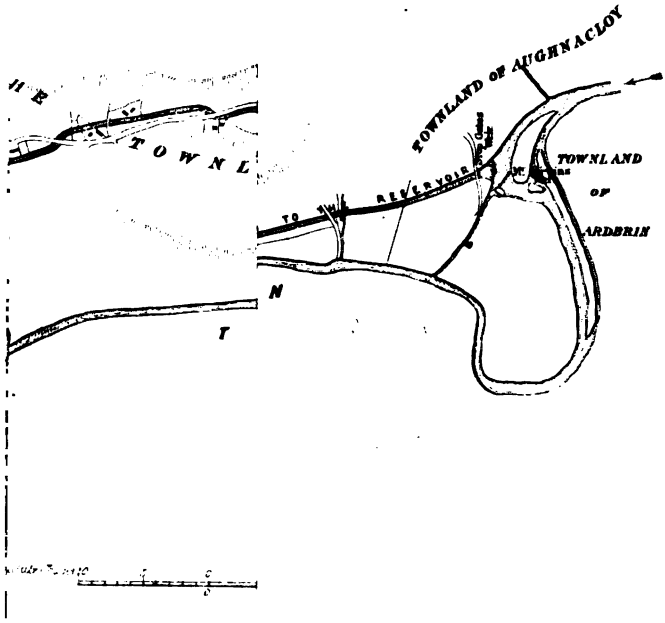
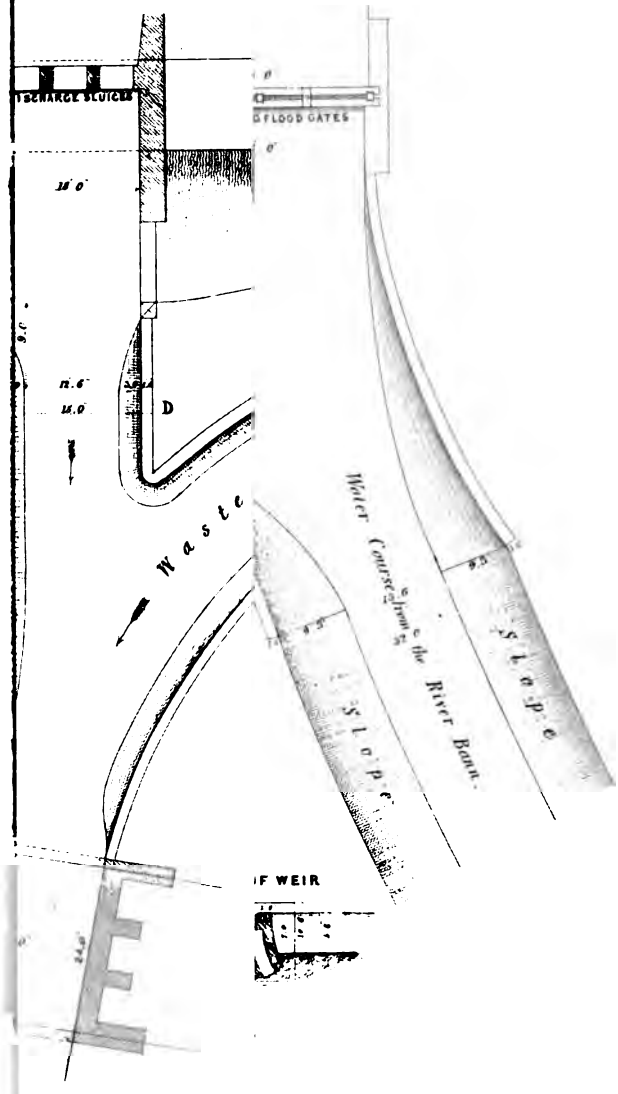
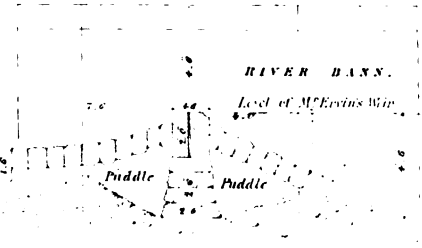

TOWNLAND OF AUGHNACLOY
TOWNLAND OF ARDBRIN
RESERVOIR
TO
N

PLATE 13.


SCHARGE SLUICES
FLOOD GATES
D
Waste
Water Course from the River Beam.
Slope
Slope
IF WEIR

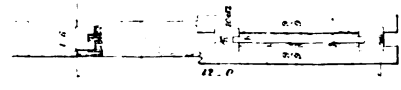
CORBET LOUGH. WEIR

SECTION.



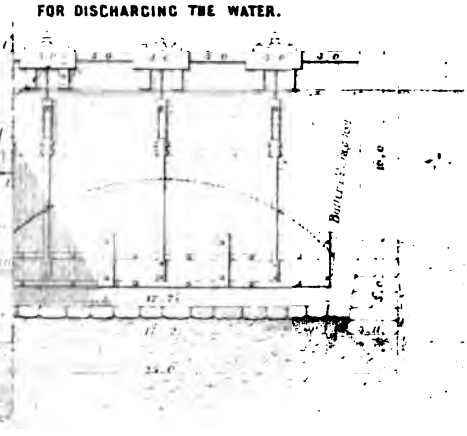
ELEVATION.

SLUICE GATES IN WEIR.



SECTION.

ELEVATION, SHEWING APPARATUS FOR DISCHARGING THE WATER.



ELEVATION, SHEWING ARCHWAY OVER DISCHARGING SLUICES.

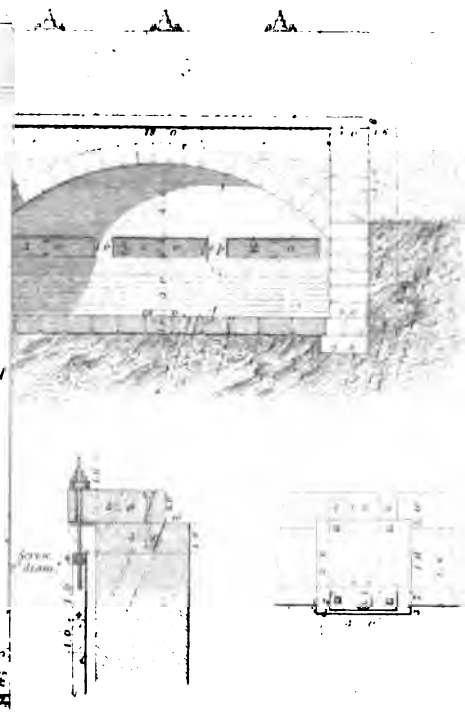
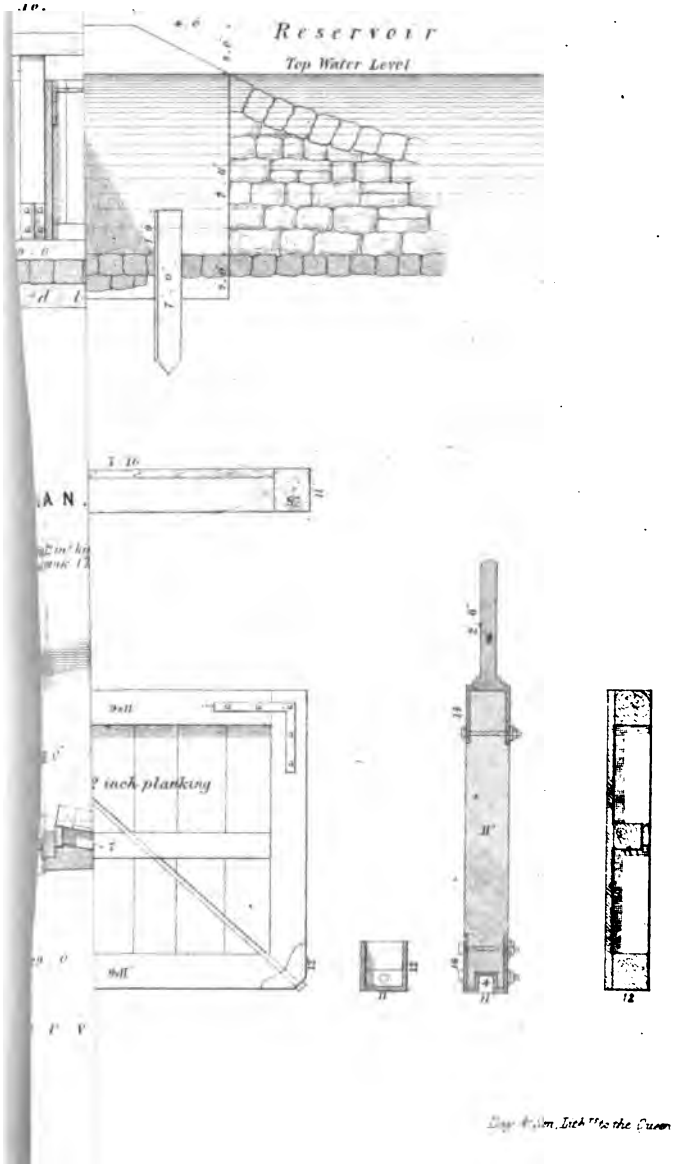


PLATE 16.

VATIO



it was obvious, that it must be larger than one from which a daily supply was regularly withdrawn for the use of the mills.

Mr. GLYNN had paid more attention to the drainage of land and to getting rid of the water, than to storing it for ultimate use. He was quite aware, that no general rule could be laid down, as to the amount of rain that could be collected; but he thought, that not more than one-third should be relied upon. The question was entirely one of locality, as to the amount of rain that fell, the quantity running off the ground, and the evaporation. He had found, that in the fen districts, not more than one-third was collected in the drains. During a period of six years, the largest quantity of rain which had fallen in one single year, in Deeping Fen near Spalding, was 34·32 inches, and the smallest was 18·1 inches. In Swaffham Fen near Cambridge, the largest quantity was 23·31 inches, and the least 14·98 inches; whereas at Kendal, the largest quantity that had fallen in one year, during a period of ten years, was 65·12 inches, and the smallest 45·73 inches, the greater part of which ran off the ground and could, of course, be collected. Mr. Glynn laid on the table the Meteorological and Magnetical Observations made in Russia during the year 1841, and directed the attention of Members to the instruments used, and to the mode of taking the observations.

Mr. BATEMAN replied to questions from Members, that during the period of the execution of works, rain-gauges were placed in various parts of the Mourne Mountains, and from them it appeared, that the ordinary amount of rain falling was from 60 inches to 70 inches per annum. The absolute quantity collected in the reservoirs, was from 48 inches to 50 inches. The result of observations made in the Longdendale district, and the adjacent hills, whence the city of Manchester was to be supplied with water, showed the average quantity of rain, falling in 1847, to be 55·50 inches, of which there flowed off the ground, as ascertained by measurement of the streams, 49·50 inches. It was however, probable, that more rain fell than was registered. In the adjacent Swineshaw Valley 49·33 inches of rain fell, and the quantity flowing off the ground was 37 inches. The rain-gauges were placed in situations varying from 500 feet, to 1,800 feet in elevation; the highest point of the hills being about 2,000 feet above the level of the sea.

Mr. HAWKSLEY said, that in the Rivington district, whence the town of Liverpool was to be supplied with water, the rain, in 1847, was 56·50 inches, and the loss by evaporation and absorption was 22 per cent., or 13 inches, leaving about 43 inches to 44 inches

flowing off the ground. The points of observation varied from 450 feet to 1,500 feet, which was the greatest elevation of the hills, above the level of the sea. The average rain-fall would probably prove to be about 50 inches, and the quantity collected about 36 inches.

Mr. HOMERSHAM said, he could not agree with Mr. Bateman, that the depth of rain falling on the land, or the flow of water off the land in this district, were so great as had been just represented. He had carefully and repeatedly examined the Longdendale district for the last fifteen, or sixteen months, and he had two funnel rain-gauges fixed near the ground in that locality, one at 1,000 feet, and another at 1,500 feet of elevation above the level of the sea; the former showed a rain-fall of only 33 inches in depth. During the past year, for such months as could be compared, the gauge on the hill, at the elevation of 1,500 feet, showed month for month, less rain fallen, than the gauge at the lower elevation; but owing to the latter gauge having been damaged, the returns for every month in the year were incomplete. In several other situations,—at the Combs Reservoir, near Chapel-le-Frith, 720 feet above the level of the sea, and Combs Ridge 1,670 feet high,—at Todd's Brook Reservoir 620 feet, and Brinks 1,500 feet high,—at the Bosley Reservoir 720 feet, and Bosley Minns 1,260 feet high,—the results obtained from funnel rain-gauges showed a less amount of rain falling on the tops of the hills, than lower down. Now according to the evidence given by Mr. Bateman on this subject at Manchester, and before a recent Parliamentary Committee, all Mr. Bateman's rain-gauge returns showed, that more rain fell on the tops of the hills than at the base: this result was contrary to the recorded experience of every meteorological writer with whose works Mr. Homersham was acquainted, and was contrary to the results of his own experiments. He believed Mr. Bateman to have been misled, owing to the faulty construction of the rain-gauges used by him. In each of his gauges was a staff $\frac{1}{4}$ of an inch in diameter; now in many of them Mr. Homersham had seen the staff standing 16 inches above the top, the gauge being only 7 inches in diameter. Experiments made by Mr. Homersham, and recently published, showed that from the drifting character of the rain falling on the tops of hills, a large quantity of water was arrested by the exposed surface of the staff, and ran down it into the gauge. The staff-gauges erected by Mr. Homersham showed, that at the tops of hills, a larger quantity of drifting rain was arrested than at the bottom; whereas the funnel-gauges without staves, used by Mr. Homersham, showed exactly the reverse, a greater quantity of rain

being indicated by such gauges at the bottom of the hill, than by those at the top.*

Mr. MURRAY alluded to the experiments made by Professor Phillips, at York, which proved the necessity of placing the gauges in proper positions, in order to ascertain accurately the quantity of rain falling. The result obtained by him, showed, that a rain-gauge placed on the ground, collected a much larger quantity of water, than one placed on the top of the Museum, and a still larger quantity than another placed on the top of York Minster. From observations made in 1834 and 1835, the ratio was found to be, 100 on the ground, 76 on the Museum, and 52 on the Minster.

Mr. BATEMAN explained, that the staff alluded to by Mr. Homersham, had, in some cases, been allowed to rise above the top of the gauge, and would, no doubt, be liable to some slight objection on that account. In the results, however, which he had just given, the staff had been fastened down, during the first half of the year, so that it could not rise at all, and during the latter half of the year, it had been entirely removed; being merely inserted at the time of taking an observation. The returns were, therefore, free from the objection made by Mr. Homersham; and they showed, that in high land, the quantity of rain increased as the altitude, up to an elevation of about 2,000 feet, except under peculiar local circumstances. Mr. Homersham had recently been engaged in drawing comparisons between the fall on high land and on low land. For this purpose he had taken the returns from a gauge placed on the ground at Rochdale, at the foot of the hills, and from another placed on the top of a house at Blackstone Edge, which was on the summit of the hills; and he found under such circumstances, that the rain appeared to be greatest at the foot of the hill. There appeared to be two other cases near Chapel-le-Frith, among Mr. Homersham's observations, which gave similar results. These, however, Mr. Bateman contended, were the exceptions to a general rule; the fact of more rain falling upon high land than upon low land, was distinctly proved by his own observations, by those made in the neighbourhood of Bolton-le-Moors, by those published by Dr. Dalton, (although the gauges had unfortunately been placed on the tops of houses,) and recently, by the extensive and very valuable researches of Mr. Miller of Whitehaven, from whose Report, dated 11th of March, 1848, Mr. Bateman read the following extracts:—

* *Vide* "Report on the Supply of Surplus Water to Manchester, Salford, and Stockport." London, 1848.

"In the last Report I observed, 'It would be premature, from the scanty data before me, to draw any conclusion as to the gradation in the quantity of rain, at these great elevations above the sea. But it seems probable, that in mountainous districts, the amount of rain increases from the valley upwards, to an altitude of about 2,000 feet, where it reaches a maximum; and that above this elevation, the quantity rapidly decreases.' The Table for 1846 exhibited the rain-fall of the summer months only, but the additional returns of 1847, obtained in every variety of season, confirm the above deductions in every essential particular, so that we may fairly assume the combined results to be indicative of a physical law, so far, at least, as relates to the particular locality in question. Thus in twenty-one months,—

			Inches.
The Valley . .	160	feet above the sea, has received	170·55
Stye Head . . .	1,290	,, ,,	185·74
Seatollar . . .	1,334	,, ,,	*180·23
Sparkling Tarn .	1,900	,, ,,	207·91
Great Gabel . .	2,925	,, ,,	136·98
Sca Fell . . .	3,166	,, ,,	128·15

"An apparent exception to this law occurs in the gauge stationed at Burnt Rigg, about midway between the top of Stye Head and the vale of Wastdale, and which, in 1847, has received about one-eighth, or 12½ per cent. less rain than the valley.

"This is the only one of the gauges situated on the slope of a mountain: it is on the windward side, and I imagine, that in such a position, eddies, or counter-currents, are produced in windy weather, which cause a less quantity of water to be deposited in the instrument, than is due to the elevation. We know, that all sloping roofs, from the same cause, materially diminish the receipts of rain-gauges.

"It will be observed, that the amount of water received by the Seatollar gauge, is invariably less than the deposit in the adjacent vale of Seathwaite, and the deficiency is pretty equable in every month of the year.

"I am unable to give any satisfactory reason for this anomaly, or to account for the very great excess of rain in this valley, over all others in the lake districts. As the gauge on Seatollar is two, or three miles distant, in a direct line, from the others, the near approach of its receipts to those of the Stye Head gauge, both about the same elevation, is rather remarkable. In 1846, the Seatollar exceeded the Stye gauge in quantity, which it should do if the assumed height be correct.

* "The height of Seatollar Common has not been accurately ascertained."

"By referring to the Table for the summer months, we find, that between the 1st of May and the 31st of October, the gauge at 1,290 feet has obtained nearly 12 per cent. more rain than the valley; at 1,334 feet, 9½ per cent. more; at 1,900 feet, 29 per cent. more; at 2,928 feet, 7½ per cent. less; and at 3,100 feet, 13½ per cent. less than the valley. In the winter months, (November to April inclusive,) the gauge at 1,290 feet has received 4½ per cent. more than the valley, at 1,334 feet, the same quantity as the valley; at 1,900 feet, 11½ per cent. more; at 2,928 feet, 38½ per cent. less; and at 3,100 feet, 42½ per cent. less than the valley.

"The difference in the proportion to the valley, between the winter and summer half-year, as shown by the Tables, is rather startling.

"When much snow falls, no doubt a considerable portion is lost to the gauge, either by its being blown out of the funnel, or by the aperture getting choked up. But I do not think, that this cause alone, is at all adequate to account for the great comparative deficiency in the winter season; for there was very little snow on the mountain tops, during the winter of 1846-7, less, I am told by one of the oldest inhabitants of the Fell dales, than he almost ever remembers. At Whitehaven, we had no snow worth naming, except on the night of the 23rd of December, when it lay to the depth of nearly an inch on the ground; but disappeared in the course of the ensuing morning.

"The late Mr. Crosthwaite of Keswick, by means of marks on the side of Skiddaw, and with the assistance of a telescope at his residence, made two, or three, daily observations on the height of clouds for several years, and it is clearly shown by his Tables, that the clouds are lowest in the three first and the three last months of the year. Moreover, Dr. Dalton affirms, that the clouds are seldom a mile high, (or little more than one and a half times the height of Sca Fell,) in our climate, in winter. Now the Doctor here probably alludes to, or at least includes, the most elevated clouds, such as the cirri, and some varieties of the cirrostratus. But there can be no doubt, that between the months of November and March, the under surface of the nimbus, or rain-cloud, (the lowest, except the stratus,) is far below the tops of our highest mountains, and I have reason to believe, not unfrequently, its upper surface also: when this is the case, the gauges on Sca Fell, Gabel, &c., will receive no rain at all, when it is descending abundantly in the valleys beneath. The lowness of the rain-cloud at this season, is, I apprehend, the principal cause of the small quantity of rain, in proportion to the valley, during the winter, as compared with the summer months. . . .

"A little consideration will greatly lessen our surprise at the enormous quantity of water deposited in the hilly districts of Cumberland and Westmoreland, and at the consequent unequal distribution of rain in the climate of Great Britain. To those unacquainted with these localities, it may be briefly stated, that the Lake District valleys radiate from a series of mountains of slate and primitive rock, having the Gabel, 2,928 feet in height, as a nucleus, or central point; and in the immediate vicinity of which are Sca Fell and Pillar, of the respective elevations of 3,166 and 2,893 feet, and Great End, Bowfell, and Glaramara, not much inferior in altitude. These mountains are distant only about thirteen, or fifteen miles, in a direct line, from the Irish Channel, and as no hills intervene, they are, consequently, fully exposed to our wet and prevailing winds, which are the south-west. The warm south-westerly current arrives at the coast loaded with moisture, obtained in its transit across the Atlantic:—now, our experiments justify us in concluding, that this current has its maximum density at about 2,000 feet above the sea level; hence, it will travel onward until it is obstructed by land of sufficient elevation to precipitate its vapour; and retaining a portion of the velocity of the lower parallel of latitude whence it was originally set in motion, it rapidly traverses the short space of level country, and with little diminution of its weight, or volume; but on reaching the mountains, it meets with a temperature many degrees lower than the point at which it can continue in a state of vapour; sudden condensation consequently ensues, in the form of vast torrents of rain, which, in some instances, must descend almost in a continuous sheet, as when 9, or 10 inches are precipitated in forty-eight hours. When we reflect, that a warm moist current, perhaps only 3°, or 4° above the point of saturation, in coming in contact with the mountain ridge, probably meets with a stratum of air 10°, or 15° lower than its own inherent temperature, we shall cease to marvel that such quantities as 4, 5, or even 6 inches of water should be deposited in these localities, in the course of a few hours. The mountains are, in fact, huge natural condensers, destined to force from the atmosphere, the mighty volumes of water requisite for the supply of our lakes and rivers."

Mr. HOMERSHAM did not contend, that a less amount of rain fell in hilly districts than on plains; he knew, that the greatest quantity of rain did fall in hilly, or mountainous districts; but his own experiments showed, and all meteorological writers agreed, that in such localities, less rain fell on the tops of hills, than lower down. The district of country, in which Mr. Hawksley had made his experiments, was to the west of Manchester, about

twelve miles, or sixteen miles distant from the sea, and it was the first high land to intercept the clouds, as they came from the ocean charged with vapour; now the Longdendale district, referred to by Mr. Bateman, was considerably to the east of Manchester, and about fifty miles distant from the sea. He contended, therefore, that no analogy existed in the amount of the rain-fall, between the two districts. The same might be said of the experiments of Mr. Miller, of Whitehaven: they were conducted among the high lands of Cumberland, at from twelve miles to eighteen miles from the sea, and within the influence of a cluster of mountains, each more than 3,000 feet in height; the greatest distance between any two of them not being more than twelve miles. These mountains were bounded to the north, west, and south, by the sea, and immediately to the east by very large lakes. Experiments conducted in such a district bore no analogy to the Longdendale district; but even Mr. Miller's experiments showed that, upon the whole, less rain fell on the tops of the hills, than at their base, and any apparent exception to this rule, arose from experiments made on comparatively low hills, in the immediate vicinity of very much higher land.

The practical question of the supply of water that could be actually obtained for domestic use from the Longdendale district, could only be solved, by ascertaining, in that immediate locality, the amount of water yielded, in a dry year, from a reservoir of a given content, fed from a given area of land.

Mr. WALKER remarked, with reference to the alleged discrepancy in the results of Mr. Bateman's experiments, that as all his gauges had graduated staves in them, and they had been placed in low, as well as in high situations, the general comparative results would not be vitiated, even if an undue quantity of drifting rain had been intercepted, by that portion of the staff, that rose above the level of the funnel. He did not think the extent of surface exposed by a staff, $\frac{1}{4}$ of an inch in diameter, could intercept enough rain to account for the difference between the results recorded by Mr. Bateman and those produced by Mr. Homersham.

Mr. POLE mentioned a fact which might bear upon the subject of the quantity of rain falling in the same locality at different levels. The district he referred to was the western, or Malabar coast of India, which was exposed, from June to September, to the south-west monsoon. The Deccan, or high land of the interior of the peninsula, was terminated on the west, by a range of precipitous cliffs, called the Ghauts, varying from 2,000 feet to 4,000 feet in height, between which and the sea, there was a flat tract of land, called the Konkun, only slightly elevated above the sea level.

Now at Bombay, and in the low district generally, the fall of rain during the monsoon, (which was, in fact, the annual fall,) was from 70 inches to 80 inches; whereas upon the range of Ghauts it was much more, the quantity there increasing according to the elevation. For example, at Mahabuleshwar, or Malcolm Peth, a sanitary station established some years ago by Sir John Malcolm, at an elevation of 3,700 feet above the sea, the fall of rain was about 240 inches, or more than three times as great as in the lower districts; so great, in fact, as to amount to a deluge, and to render the place uninhabitable during the monsoon. At Khandalla, another point in the same range of hills, but only 1,700 feet high, the fall of rain was about a mean between the two extremes just mentioned. The differences here were so wide as to admit of no dispute as to the accuracy of the rain-gauges. From the peculiar nature of the weather in these localities, it might be a question, whether they could be fairly placed on a parallel with districts in Europe; but the facts were extraordinary, and deserved to be recorded.

Sir CHARLES MALCOLM confirmed Mr. Pole's statements, adding, that the maximum fall of rain in the districts referred to, was at a level of about 4,000 feet, and that above that elevation it appeared to decrease; thus demonstrating the existence of a law analogous to that given by Mr. Bateman, as the result of Mr. Miller's experiments upon the lakes in the north of England.

Mr. HOMERSHAM said, the results published by Colonel Sabine, as to the amount of rain among the hills at St. Helena,* proved less rain to have fallen on the tops of the hills, than lower down; and Dr. Dalton, as well as all other meteorological writers, had demonstrated the fact by direct experiments.

Mr. HAWKSLEY, in reply to further inquiries, stated, that on the lands whence the water for the supply of Liverpool was to be obtained, and which comprised the elevated range of hills in the vicinity of Rivington Pike, six gauges, manufactured by Troughton and Simms, had been erected. The funnels were 10 inches in diameter, and the readings were given from a scale attached to a glass tube. In the year 1847 the fall of rain, as ascertained from the average of all the gauge instruments, was about 56·50 inches, varying from about 49 inches on the low ground, to 61 inches on the high ground. According to present observations it appeared, that the greatest

* *Vide* "Observations made at the Magnetical and Meteorological Observatory of St. Helena, 1841, by Captain Lefroy, Director of the Observatory at St. Helena." Published by order of Her Majesty's Government, 1847.

amount of rain fell, in that district, at an elevation of about 1,000 feet above the sea. It was probable, that this altitude corresponded, very nearly, with the mean height of the densest portion of the rain-cloud. The loss from evaporation had been ascertained to be from 20 to 25 per cent., the inclination of the ground being very rapid, with little table-land, and the surface consisting chiefly of a thin vegetable covering, reposing on a stratum of yellow clay, overlying the millstone-grit formation.

Mr. Hawksley did not consider it safe to rely upon proportions obtained from previous observations, in determining the amount of water which might be collected into reservoirs; it was better to ascertain the actual number of inches evaporated. He had found that, whilst on the Lancashire hills more than two-thirds of the mean quantity of rain could be collected, on the Lincolnshire wolds it would not be possible to collect even one-third. In both districts the evaporation amounted to 12 inches, or 14 inches, and this result corresponded, very nearly, with Mr. Dickenson's observations in Hertfordshire.* When, however, the fall of rain was less than the mean amount, the evaporation was also less, for the obvious reason, that during the prolonged period of drought, no water was present for the atmosphere to act upon. Under this condition, grasses and plants depending for their nourishment upon the superficies of the land, withered, and in some instances, ceased even to live.

The Liverpool water-shed had a westerly aspect; it was situated twenty miles from the Irish Channel, and commenced at an elevation of 500 feet above the sea, afterwards attaining, in some places, an altitude of about 1,800 feet. Now it was worthy of remark, that whilst on the Cumberland mountains, there was an average annual precipitation of 100 inches, or 120 inches, and on the Liverpool water-shed of, at least, 50 inches, on the east side of the kingdom, the average was not more than 22 inches, and in the midland counties it was under 30 inches. A fall of rain of even less than 15 inches had been known to occur in the fen districts of Lincolnshire.

With respect to the dispute amongst meteorologists, as to whether most rain fell at the bottom, or the top of a hill, Mr. Hawksley had no doubt, that in attempting to generalise on this subject, both parties had fallen into an error. The greatest fall, 'cæteris paribus,' would take place at the mean height of the rain-cloud; but locally-produced currents would necessarily exercise an influence on the result. If the hills were low, or only moderately high, the

* *Vide* Minutes of Proceedings Inst, C.E., 1843, vol. ii., p. 159.

amount of rain would generally increase, from the foot to the summit; if they were very high, so as to pierce and pass through the clouds, less rain would fall on the summit, than at some distance down the declivity; but the exact point must depend on the climate, the temperature, and other circumstances. The problem did not, therefore, admit of a general solution.

Mr. BATEMAN was happy to find, that scarcely any difference existed between his observations and those made by Mr. Hawksley. The average of Mr. Hawksley's returns, for 1847, was 56·50 inches, whilst Mr. Bateman's was 55·50 inches. The returns of several gauges in the Longdendale district for 1847 were:—

	Inches.
At 500 feet above the sea. . .	46·6
„ 800 „ „ . . .	50·5
„ 1,700 „ „ . . .	52·1
„ 1,700 „ „ . . .	56·5
„ 1,800 „ „ . . .	62·1

By a careful examination of the water flowing off the ground, Mr. Bateman was convinced, that had there been gauges placed on the highest part of the hills, the amount of rain falling would have been shown to be still greater.

Mr. HOMERSHAM was not convinced by these returns; on the contrary, he contended, that the amount of rain falling decreased with the altitude, that all writers on meteorology, except Mr. Miller, agreed on this point, and his own observations confirmed it. He had two gauges in the district whence Mr. Bateman's returns were made, and they showed only 33 inches of rain.

Mr. BATEMAN concluded, that in this case there must be some great error, as these returns of 33 inches of rainfall, were from a district from which it was clearly shown, that 49·50 inches had actually flowed off the ground. This was ascertained, by every stream being measured daily,—some regularly once a-day, some twice a-day, at the same hours,—and the river into which all the streams flowed, being measured three times a-day. The measurement of one stream, corroborated the accuracy of the observations upon the others, and they all agreed in giving nearly the same quantity flowing off the ground. The general result might be a little above, or below the truth; but it was a close approximation.

Mr. BIDDER said, he had not made any direct observations upon the district in question; but from the general results, he believed the opinion advocated by Mr. Homersham to be incorrect.

Mr. HOMERSHAM said, that from April 1844 to April 1845, the

reservoir of the Ashton Water Works collected all the water flowing off its drainage ground of 378 acres; and by accurate experiment this was proved to be only equal to a depth of 15·50 inches over its surface. The reservoir was within four miles of the Longdendale district, and its drainage-ground was about 800 feet above the level of the sea: this proved that much less water flowed off the ground, than Mr. Bateman's experiments seemed to indicate. He considered, that two, or three measurements of a mountain-stream per day, as practised by Mr. Bateman, would not give a true indication of the quantity of water flowing off the land, owing to the irregularity in the quantities flowing down such streams in a very short space of time: a flood would sometimes only last for one hour, or two hours, and a measurement taken at such a period would vitiate the whole results.

Mr. BEARDMORE said, that he must protest against Mr. Homersham's conclusions, as contrary to the general opinion of Engineers, and to Mr. Beardmore's own experience. Colonel Sabine's experiments were, doubtless, capable of some explanation, as it was improbable, that the results obtained by so eminent an authority, as to the amount of rain falling in hilly districts, should be contrary to facts familiarly known to every Engineer who was engaged in forming reservoirs for storing water. He had examined the amount of rain-fall on various parts of the Pentland Hills, and had made the most minute experiments on the proportion flowing off the ground. The results were, briefly, that whilst the mean rain-fall in Edinburgh, at about 200 feet above the level of the sea, for the years 1844, 1845, and 1846, was about 30 inches at the Glencorse Reservoir, in the Pentland Hills, distant only nine miles from the sea, and about 700 feet above its level, the mean rain-fall, for the same period, was 37·4 inches, and at Carlops, similarly situated but 900 feet above the sea, the fall was 49·16 inches. Numerous gauges which had been strictly kept, in the Glencorse district of the Pentlands, during December, January, February, and March 1846–47, indicated similar results. That period happened to be singularly propitious for experiments, as it was drier by 66 per cent. than any previous winter season for at least sixteen years. The results gave, for a district about 1,000 feet above the sea, and immediately adjacent to Glencorse Reservoir, 51 inches of rain.

The strongest proofs, however, were given by gauging every drop of water that fell into the reservoir, which was kept under diurnal observation for that purpose. It thus appeared, that during the four winter months above named, rather more water

was actually delivered into the reservoir, than was indicated by the rain-gauge kept at the same level; the registered fall being 4·35 inches, whilst the water gauged was 4·53 inches; a result fully borne out by the upland gauges, which gave about 5·5 inches, for the same period. That as much water was available at any given point, as was indicated by the rain-gauge at the same place, was proved by other gaugings taken at a different point in the same district; all the results showed, that the rain-fall was greater on the higher slopes. As to the method of gauging by a notch-board, however accurate it might be in ordinary cases, it was manifest, that, during heavy floods, a large amount of water must pass off without due observation, from the velocity which the whole mass of water acquired, and which rendered the ordinary formula useless. As the greater proportion of rain passed off in a state of flood, when the error would much reduce the real quantity, it was fair to conclude, that more water really passed off than was ordinarily supposed; and his experiments, at various times, seemed to establish the fact.

He did not think, that any fixed rule could be laid down, as to the amount of storage-room required in proportion to the area of drainage ground. This must be greatly influenced by the amount of rain-fall, the contour and declivity of the ground, and above all, by its nature;—flat peat districts, offering the utmost contrast to precipitous rocky hills, where the water descended to the lower valleys immediately after storms. Again, in large districts, the time during which the stored water would be required for the supply of mills, would evidently vary, and where, as in the case of the Bann Reservoirs, the periodical occurrence of a drought was to be provided against, a large amount of storage-room was of the utmost possible advantage.

Mr. HOMERSHAM said, the practical question resolved itself into this: what quantity of water had been regularly yielded for consumption throughout a year, by a reservoir of a given capacity, fed from a given area of drainage-ground? The example he had quoted of the Ashton Water-works Reservoir was a practical case, and he contended, that such were the only sure guides to be depended upon.

Mr. WALKER observed, that the principle of large impounding reservoirs ought to apply to all large towns; for the rain stored in a wet season, might then supply the deficiencies of one, or two succeeding dry seasons.

Mr. HOMERSHAM remarked, that the amount calculated upon by Engineers was based upon the hypothesis, that two-thirds of the fall of rain flowed off the ground.

Mr. HAWKSLEY said, that Mr. Homersham misconceived what Engineers really did understand upon that subject; that which was the rule for the west coast of England would not apply to the east coast, where the rain-fall was only 22 inches, or 24 inches, and where, occasionally, only 14 inches of rain had fallen. He instanced a case, in which, out of a fall of 23 inches of rain, 15 inches had been evaporated, or absorbed; thus showing a loss of two-thirds with respect to store reservoirs; where one on the wettest part of the west coast, of a capacity equal to a supply of ninety days, would be sufficient, another, on the east coast, would require to be of dimensions equal to a supply for one hundred and eighty days, or more.

Mr. MCCLEERY, through the Secretary, said, that, according to Townsend, the fall of the Lower Bann was 39 feet 3 inches, to the height of ordinary spring-tides, when the Lough Neagh was at its lowest.

	Ft.	In.
At Salmon Leap . . .	4	7
At Loughang . . .	1	3
At the Vow . . .	2	11
At Movannahed . . .	12	0
At Pértna	18	6

The map in the Bog Reports gave the fall at Pértna as only 16 feet 6 inches; but this was, probably, a misprint. Mr. Townsend stated the highest water-flood to be 46 feet 3 inches above the sea,—a difference of 7 feet,—which the greatest rise of Lough Neagh had never exceeded. On the same authority, the distance from the Bar of Toome to the Salmon Leap was twenty-four and a-half Irish, or about thirty-one statute miles: the area of Lough Neagh was 97,272½ acres, and that of Loughby 25,551 acres. Lieutenant Graves made a survey of Lough Neagh by order of the Admiralty, and in his chart it was stated, that the fall of the Lower Bann, when at summer level, to low-water mark in spring-tides, was 48 feet, and that in winter, the lake rose from 6 feet 7 inches to 8 feet.

Mr. BATEMAN, through the Secretary, said, that the extraordinary discrepancy which appeared to exist between the observations of Mr. Homersham, and those of other persons, had led him to examine the nature of the rain-gauge used by Mr. Homersham, when the cause of the anomaly was at once apparent. The gauge was a mere evaporating vessel, as the whole apparatus was placed above the ground, and the rain, which was collected within a funnel 9 inches in diamater, was conveyed by a short pipe at the bottom,

into an open glass bottle, or receiver, of about the same diameter as the funnel. The surface of the water not being covered by a float, was in contact with the external air, and was, therefore, liable, in a great degree, if not entirely, to be affected in the same manner as the surface of an open pond. Evaporation from a water surface varied from between 20 inches and 30 inches to 50 inches per annum, the evaporation rapidly increasing with an increase of elevation. The quantity of water measured in Mr. Homersham's gauge, was the mere residuum, after evaporation had carried off as much as possible. The case was analogous to that of a common tea-kettle. The metal funnel and glass receiver formed the kettle: the dry rarified air of an elevated district, the currents of dry wind and the solar heat, performed the offices of the fire: the open funnel and communicating pipe acted as the lid and spout of the kettle, through which the water, converted into steam, regularly escaped.

Mr. Homersham adduced three instances of observations made with these funnel-gauges — at Woodhead, in Longdendale, — at Todd's Brook,—and at Combs. At Woodhead the rain appeared to be 33 inches in a district, from which, as already stated, 49·50 inches had actually flowed off the ground. Now adding to the 33 inches the amount due to evaporation at an elevation of 1,000 feet, the difference was at once accounted for. Supposing the real evaporation from water, at this height, to be 40 inches, half might fairly be taken as the amount evaporated from the water within the gauge, (as it was to some extent covered, although not excluded from the air), which would thus give a total rain-fall of 53 inches. Of the two gauges of Mr. Bateman, the nearest to Woodhead, which was three miles distant, showed, at an elevation of 800 feet, 50·50 inches, whilst the other, which was two miles and a-half distant, and at an elevation of 1,800 feet, showed 62·10 inches.

At Todd's Brook, the rain at the foot of the hill and on the top, appeared to have been ascertained by similar gauges. Corrected by the probable amount due to evaporation, the returns would stand thus:—

	Water measured. Inches.	Evaporation. Inches.	Total Rain-fall. Inches.
At Todd's Brook Reservoir, 620 feet above sea,	38·39	+ 10 for evap.	= 48·39
At the top of the hill, 1,500 feet	29·50	+ 20 „	= 49·50

At Combs Reservoir the rain at the foot of the hill was ascertained by a staff-gauge, which Mr. Homersham contended, showed more rain than fell, but which he, nevertheless, compared with a funnel-gauge at the top. Allowing for the evaporation of the funnel-gauge, the returns would be:—

		Total Rain. Inches.
Combs Reservoir,	720 feet above sea	51·30
„ Ridge,	1,670 „ 35·85 in. + 20 in. for evaporation	= 55·85

An occasional instance of less rain occurring on high land than on low land, like the one alluded to by Mr. Miller of Whitehaven, might, certainly, be met with; but the great weight of evidence was in favour of the conclusion, that up to a certain height within the region of the clouds, the rain was greater in proportion to the greater elevation of the ground. It was no less certain and curious, that in a direct line upwards, the greatest fall was upon the ground; —that there was less rain upon the top of a house than at the bottom, and still less upon the top of a church. This fact had misled many meteorologists into the belief, that the same rule applied to increased elevation of land.

If one of Mr. Homersham's funnel-gauges were placed in an exposed situation on Epping Forest, where the amount of rain was less than the evaporation from water, and visited at the end of a year, in the months of August, or September, Mr. Bateman had no doubt it would be found entirely empty.

Mather's Elastic Metallic Piston.

After the Meeting, Messrs. W. and C. Mather exhibited and described their Elastic Metallic Piston.

The main feature of this piston consisted in the combination of two helical coils, one placed within the other; the internal one giving the elastic power vertically and horizonally, the external case transmitting that power to the cylinder, and receiving the wear and tear against it. The essential elements of a good metallic piston, viz., horizontal and vertical elasticity, were thus secured in the formation of a perfect elastic metallic packing.

The great superiority of this improvement, was its simplicity; it only consisting of two pieces of metal, having vertical and horizontal elasticity in due and proper proportions, in simple combination, the horizontal elasticity keeping the packing steam-tight against the cylinder, and the vertical elasticity keeping it steam-tight between the top and bottom plates of the piston-block, thus allowing no space for the steam to escape in any direction. Another advantage was to be found in the mildness of the elastic pressure, which was generated by the circumference, and not by the diameter; thus creating but little friction, and consequently economising power and the wear and tear of the piston and cylinder. The internal helical

coil, if straightened out, would be equal to nine times the diameter of the cylinder.

It should also be observed, that the elasticity was perfectly circular in its action, always tending to wear the cylinder to a true circle, should it at first be otherwise. As the piston was self-adjusting, it accommodated itself to the inaccuracies of the cylinder, whether oval, or tapering, to a far greater degree than any other piston hitherto known. The small space occupied by the packing around the circumference, allowing a much larger water-way, rendered this piston superior to any other for air and cold water pump-buckets, for which purpose the external case was made of brass. The engine-man had no power of altering the elasticity of the packing, consequently, by keeping it clean, it would continue to work well until the casing was completely worn through. The steam, even if it got behind the packing, could not introduce itself into the body of the piston-block, the cover being accurately ground upon the outer rim of the block, and firmly screwed down by bolts near the external diameter, thereby preventing all ingress of steam into the interior of the piston, and consequently, the great strain upon the bolts, at each return of the stroke, in the common pistons.

It was constructed in the following manner: a cylinder of cast-iron of sufficient length was bolted to the face-plate of a lathe, and small holes were drilled at the starting and stopping places for the cutting tool. A cut was made in an oblique direction, by the ordinary traverse of a slide lathe, until nearly half way across the breadth, the cutting tool stopping at the hole drilled in that situation; a second cut was then made in a similar manner, but in a more oblique direction, by changing the speed of the traverse motion; and lastly, a similar cut was made from the middle to the outer edge; thus leaving the vertical elasticity in the part intended for the helical coil. Pieces were then cut off the ends of the coil to enable it to contract by a hoop, and thus to form the horizontal elasticity, the diameter of the hoop representing the cylinder in which the packing was required to work.

The external casing was simply a ring of cast-iron, or brass, with flanges on each edge projecting inwards. It was bolted against the face-plate of a lathe, and roughed over by the turning tool inside and outside: it was then cut with a small, or thin tool, once and three quarters round to the opposite edge, commencing and ending just within the flanges; the ends were next liberated by sawing through, then cramped together and made fast by the outside, and retained there until the edges and the inside were finished: the

stopping pieces were then fitted, and it was ground on the edges upon the block and cover in which it was to work. The case was now placed upon the block, and pieces of card-board, or thick paper were screwed between the block-case and cover, to hold it fast while the finishing cut was taken over the external circumference to the exact diameter of the cylinder. It was now ready to receive the internal coil, the flange of the casing, entering the part cut out of the internal coil, which was then screwed round until it came within the flanges of the casing, the joint opening considerably by its own inherent elastic power.

Before placing it in the cylinder, it must be coiled up by the hoop to the diameter of the cylinder, and when thus contracted, made fast, by screwing down the cover, upon pieces of card-board placed between the cover and the packing, nipping it sufficiently tight to prevent it from expanding when the hoop should be taken off. It could then be placed within the cylinder with perfect ease: the cover was unscrewed, and the card-board taken out; the cover was then screwed home upon the block, leaving the packing at full liberty to expand and come into contact with the cylinder with a mildness of elasticity peculiar to this form of metallic packing.

In all cases where segments were used, the cylinder was continually wearing into an irregular form, and required to be re-bored; for the segments, however small, could not be made to fit varying diameters; therefore causing a loss of steam, and consequently, of power. When two, or three annular rings, with one opening in each, were used, the elastic power was generally obtained by screws made to press against a V bit, the screws being acted upon by a plain spring of steel: the elastic power was very limited and stiff, and there was always a tendency towards an oval expansion, which caused the cylinder to wear irregularly. There was no vertical elasticity in either the segments, or the annular rings.

April 18, 1848.

JOSHUA FIELD, President, in the Chair.

In accordance with the provisions of Section xi., Clause 4, of the Bye-Laws, the following proposition was brought before the Meeting, by the Council, and being duly moved and seconded, it was resolved:—"That the evening of Tuesday, the 30th of May, be devoted to the President's Conversazione, and that it be held in the rooms of the Institution."

No. 790.—"Observations on the Resistances to Railway Trains at different Velocities."* By Daniel Gooch.

[ABSTRACT.†]

These observations were founded on a series of experiments performed on the Great Western Railway, by means of a dynamometer constructed at Swindon, in which all the required results were registered, upon a large scale, on the same roll of paper, thus exhibiting at one view, and in the same period of time, the tractive power exerted upon the train, and the force and direction of the wind. The registration of the results was made upon the paper at every sixteenth part of a mile, and the time was registered in correspondence with the distance traversed, during every fifth part of a second. The dynamometer spring used was 7 feet 6 inches in length, and was very carefully made. It was only necessary to count the number of seconds, or fractions of a second, in one, or more of the distance divisions, and the speed was accurately ascertained. The force and direction of the wind was ascertained by a wind-gauge, placed 5 feet above the top of the carriage, with the connections brought down to pencils which indicated, on the same sheet, all the results. Indicator-cards were also taken, simultaneously, from the steam cylinders, as frequently as was practicable, but not continuously, as it was a service of some danger, the experimenter being obliged to sit on the buffer-beam of the engine, whilst it was progressing at a velocity of 60 miles per hour, and in that position, to take off four sets of cards in three-quarters of a minute. The spot selected for performing the experiments was one mile of railway, perfectly straight and level, and nearly flush with the surface of the ground; the height of the trees, hedges, and every intervening object which could affect the influence of the wind, was clearly marked in the plan which accompanied the Paper. The experimental train consisted of first and second-class carriages, each on six wheels, 4 feet in diameter, taken from the working stock, and loaded with iron to represent a fair load of passengers, giving a gross weight, for each, of 10 tons. The experiments were tried with various weights and speeds up to 100 tons and to 62 miles per hour, and the results were classified and arranged in a tabular form, with copious explanatory headings, so as to render reference to them perfectly easy.

* The discussion upon this Paper extended over portions of four evenings, at different periods, but an abstract of the whole is given consecutively.

† In consequence of the Paper, with the experiments, having been printed and published elsewhere, it is, in accordance with the provisions of the bye-laws, precluded from being printed in extenso in the Minutes of Proceedings.

The Author first reviewed the deductions of Mr. Wyndham Harding's formula,* and gave his reasons for dissenting from that formula. He then critically examined several experiments recorded in the Tables, stating all the exceptions that could be taken to them; showing also, that although there was a difference of as much as 52 per cent. between the resistances deduced from Mr. Harding's formula, and the experiments made by Mr. Gooch, that difference might be accounted for by the methods employed by Mr. Harding, but which were objected to as calculated to produce erroneous results; viz.,—allowing carriages to run down inclines by their own gravity,—using wheels 3 feet in diameter instead of 4 feet, —having a much greater length of train for the wind to act upon, &c. He considered the effects of a side wind against a train, in driving the flanches of the wheels against the rails; and argued, that the length of a train of carriages was much more important than its weight.

The Author did not offer any formula that should be applicable for calculating the resistance of all railway trains, but his Tables gave examples of almost every case that could occur, and thence data could be supplied, for those who wished to carry the investigation further, and make a formula for themselves. He arrived at the conclusion, that in practice, the friction of the axle-journals was not a constant quantity at all speeds, and he thought, that the number and diameter of the wheels in a train, in proportion to the weight, would form elements in any general formula. He showed by experiments, that the total atmospheric resistance to a train weighing 50 tons, differed but slightly from that which was offered to a train of 100 tons, if the carriages were small and the train long in the one case, and the reverse in the other case. The general result of the diagram of resistance with trains of 100 tons and of 50 tons showed, that the resistance calculated by the narrow-gauge formula with a train of 50 tons, running at a velocity of 62½ miles per hour, was 37 lbs.: with a train of 100 tons, at 61 miles per hour, it was, by the same formula, 31½ lbs. On the broad gauge, the resistance to a train weighing 50 tons, at 62½ miles per hour, was under 23 lbs., and with a train weighing 100 tons, at 61½ miles per hour, it was 22½ lbs.

The Author concluded by saying, that it appeared to him necessary, before any general formula for calculating the resistances to railway trains could be made, that the value of the following

---

* *Vide* Minutes of Proceedings Inst. C. E., 1846, vol. v., p. 404.

elements, necessary in such formula, should be determined by experiments:—

1. The axle-journal friction, at different velocities and with different weights, per square inch of journal surface.

2. The resistance to the rotation of the wheels and axles, per pair, at different velocities, and with different diameters.

3. The resistance due to the rolling of the wheels upon the rails, with different weights upon them, and with different diameters.

4. The resistance due to the passage of the train through the atmosphere, at different velocities, with different proportions of weight, and of length and breadth of train.

5. The resistance due to the oscillation, or unsteady motion of the train, at various speeds.

The Author considered, that all these values might, by careful experiment, be determined with a considerable degree of accuracy.

The Paper was illustrated by a complete series of diagrams.

Mr. Scott Russell said he had examined the elegant and extensive apparatus prepared for instituting these experiments, which had been evidently provided on a most liberal scale. He regretted, that a similar course had not been followed on other railways, as he had no doubt most of the companies would, for purposes of this kind, be quite ready to place all their means at the disposal of the Engineers; for there were few of them who would not find it to their advantage to ascertain definitely the measure of traction, which, after all, was the cost of doing their work.

Up to the date of Mr. Wyndham Harding's Paper, and even to that by Mr. Gooch, he had considered it desirable to possess experiments of a more general character, than those presented in the present Paper. He had, therefore, thought it better to make experiments on the ordinary working of ordinary trains, under ordinary circumstances, so as to discover something like a general principle applicable to all railways, and thus to enable an Engineer to estimate and provide his working power, with something like certainty. This was what every Engineer required in the first instance, and this Mr. Harding's Paper and Mr. Scott Russell's former and recent experiments had been intended to provide. Now he submitted, that the experiments of Mr. Gooch were directed towards ascertaining the minute differences produced by slight variations of circumstances and of machinery, rather than to establish the general principle. It might, hereafter, become very important to determine these differences minutely, but at present,

the general question was much more urgent. Mr. Gooch had selected a special line of one mile, a special engine, and an assorted train of carriages, and from these he gave a set of selected results. As selected results these were most valuable; but he thought it necessary specially to guard the Meeting against receiving them, as indicating fairly the general law of the ordinary working of railway trains.

In his own experiments, Mr. Scott Russell had used every variety of propelling power, under all ordinary circumstances of trains, and he had found, that in forty-two experiments extending to a speed of 60 miles per hour, the same general law, expressed by the formula, fairly represented the results. Instead of thinking, that the experiments of Mr. Gooch overturned the formula, he thought they established it; only in applying the formula for wheels 4 feet in diameter, instead of wheels 3 feet in diameter, the amount of resistance from axle friction and other causes, would have to be reduced in some proportion to the increased diameter. This being done, the experiments of Mr. Gooch seemed to confirm the formula.

He objected to the use of oil cylinders with the register dynamometer; he was informed, however, that their use was now abandoned. From the uniformity of the indications, which were so much more regular than his own, he was led to infer, that the part of the line where the experiments were tried, must have been in exceedingly good condition.

He hoped, that the remarks he had made would not be considered as at all depreciating the value of Mr. Gooch's experiments; he merely wished to discriminate the results, and he hoped the experiments would be continued and extended, both by Mr. Gooch and other Engineers.

Mr. WYNDHAM HARDING said, it was necessary for him to preface his observations on the Paper, by a few brief introductory remarks, in order to recall more vividly to the recollection of Members, the past and present state of the question of resistances. The estimate of resistance given by most of the former writers, was about 7 lbs. per ton of an ordinary passenger train, without any great regard to velocity; this, therefore, was assumed as a datum, on which all calculations as to locomotive power were based. After a time, it was, however, suspected, that some error existed; and when, in 1845, the atmospheric system of traction was brought before Parliament, it became more important to ascertain the resistance correctly, the area of the tube limiting the propelling power.

During the investigation on the Newcastle and Berwick line, the

estimate of resistance adduced by the advocates of the atmospheric system was, that at a velocity of 60 miles per hour, an ordinary passenger train, weighing 40 tons, would, under favourable circumstances, show a resistance of 17 lbs. per ton. That estimate was, by some Engineers, considered too low, and in 1846, Mr. Harding collected the various experiments made by himself and others, and endeavoured to treat them in such a manner as to obtain a correct expression of the resistance. The result of his investigation was, that under similar circumstances and conditions, the estimate of resistance should be nearly 30 lbs. per ton. It was, evidently, of the greatest importance to account for this vast discrepancy of opinion, as the calculations for the expenditure of power and the question of the gradients of railways almost entirely depended upon it. Taking, for instance, the case of an atmospheric tube, 15 inches in diameter, working under a pressure of 10 lbs.; now at the estimate of a resistance of 17 lbs. per ton, a train of 100 tons could be propelled; but if, according to Mr. Harding's views, the resistance was increased to 30 lbs. per ton, a train of only 60 tons would be propelled at the same velocity in each case.

It must be clear, that this question of the estimate of resistance applied to every kind of traction, and, therefore, Mr. Harding regretted, that by some expressions in the Paper, the controversial question of the merits of the broad and narrow gauges had been attempted to be introduced. Mr. Harding would, however, endeavour to account for any discrepancy between his views and those of Mr. Gooch, without reference to the gauges, and as the experiments were, he was sure, accurately recorded, it would not be difficult to show, that the discrepancies were not so wide as had been presumed; and secondly, that they might be accounted for by the difference of the circumstances under which the experiments were conducted.

With respect to the "red-line law of resistance," stated by Mr. Harding to have been laid down by Mr. Brunel, Mr. Samuda, and Mr. Gooch, but which was repudiated in the present Paper by Mr. Gooch, it was impossible to read certain portions of the evidence given by those gentlemen before the Parliamentary Committee on the Berwick and Newcastle Railway, in 1845, without coming to the conclusion, that Mr. Harding was justified in drawing the inference he had done, in his former Paper.

As to the objections to the experiments upon the atmospheric railway, Mr. Harding had carefully revised his calculations, and must contend for their accuracy, which could be tested by any one who would afford the time to examine them.

To the more general objection to the atmospheric experiments, that the resistance was not taken at a point where the resistance and the propelling force, as indicated by the barometric pressure, were in equilibrio, he would reply, that the conditions under which the experiments were necessarily made, were those of a varying velocity with a progressive fall of the barometer. The only true point at which the observations could be taken was at the moment of the highest velocity, comparing it with the resistance at the same moment. Up to that period, the propelling force was greater than the resistance, as was proved by the increase of the velocity; it was also evident, that afterwards, as the velocity decreased, the propelling force was diminished. If any reproach could be fairly made, upon that score, to his experiments, it should be, that he had under-rated, rather than over-rated, the resistance.

With regard to the objections made to Morin's dynamometer, although he had not himself tried the instrument, he was satisfied, from the observations of Mr. Scott Russell and others, that the results furnished by that instrument could be perfectly depended upon.

Mr. Harding could not seriously entertain the objection, that a shower of rain fell during the experiments, for surely such an occurrence could not materially increase the resistance to a train, when running at a velocity of 50 miles per hour.

Now as to the experiments on the inclined plane. These were not made by himself alone, but by others of the highest authority,—by Mr. Rennie, Mr. Locke, and Mr. Woods, and by Mr. Scott Russell,—and they had been repeated on almost every line of railway, with the same general results. In coming down an incline, (the Croydon incline to London, for example,) the train was found to attain a uniform velocity, which was always under 40 miles per hour, that being the point where the resistance and the propelling power balanced each other. He thought, that the truth of the general results thus obtained could not be disputed, for care was, of course, taken to place the engine and the heaviest carriages in the front of the trains.

In conclusion of this part of the subject, he must contend, that the objections made were aimed at inconsistencies of detail and discrepancies, which must ever be found to exist in any numerous series of experiments, but that they did not invalidate the correctness of the general results arrived at.

He would now call the attention of the Meeting to the different methods in which the experiments of Mr. Gooch had been conducted, from those employed in his own, or rather in those from which he

had deduced his conclusions; for although certain experiments on the broad and narrow gauges were made by himself, there were many others due to the Committee of the British Association, which included the names of Mr. Locke, Mr. Rennie, and Mr. Woods,—to Mr. Nicholas Wood,—and to Mr. Scott Russell. Those experiments were made on various lines of railway, and under a great variety of circumstances, yet the results presented a uniform velocity. Now the experiments of Mr. Gooch, were, on the contrary, conducted not only upon one particular line, remarkable for its straightness and smoothness, but also upon a measured mile of that line, so smooth that the dynamometer, which occasionally varied between London and Slough, was not at all affected,—the carriages were selected, and in the best possible condition,—and everything was arranged so as to give the least amount of resistance. These experiments were also made on trains much heavier than in Mr. Harding's experiments, so that the resistance per ton was, necessarily, much lower. In the latter, no train exceeded 64 tons, whilst in the former, there were none below 100 tons, and some were as much as 150 tons, although on the diagrams they were called trains of from 50 tons to 100 tons only, 50 tons being subtracted from each, as the weight of the engine and tender. In his experiments, the resistance of the atmosphere to the whole train was given, whereas in those of Mr. Gooch, it was the resistance of the engine and tender only, which did not afford the same elements of comparison. Again, it was a mere delusion to compare a formula adapted for trains up to 64 tons, to trains of 150 tons, for it was very unlikely, that the same formula would apply, without correction, to trains so much heavier. The formula gave the accurate resistance per ton for each train, but as the resistance in the front of the train was a fixed quantity, it was evident, that the greater the number of carriages, the less would be the resistance per ton. He demurred, therefore, to the comparison sought to be established by Mr. Gooch, between the results given by the formula, when calculated for a weight of 150 tons, for which it was not proposed, and the actual resistance, taken behind the engine and tender, offered by those trains in his experiments. Still he had, out of curiosity, applied the formula to these heavier trains, and then instituting a comparison between the results given by it, and those obtained by Mr. Gooch in his experiments, he had found, that in the uniform velocities of the latter the resistances calculated from the formula nearly approached those actually observed; but that in the accelerated velocities, the formula showed a much higher resistance than he had ever believed to have existed. If then, any conclusion

could be drawn, it would be in confirmation of the formula, when limited to those cases for which it had been laid down.

As to the assertion in the Paper, that the resistance on the broad gauge was 52 per cent. less than on the narrow gauge, it was arrived at by the impeachment of experiments upon which he and several eminent authorities placed full confidence, and by the reliance upon experiments which were, in his opinion, open to much criticism, when sought to be applied as a basis of practice. Such experiments would, no doubt, materially assist in analysing resistances, but they could not be applied as a basis of practice, for it was illusory to compare the resistances obtained at the tail of a train, proceeding smoothly over a measured line of railway, with those which were encountered by the whole of a train running over railways in ordinary condition. Taking also into account all the casualties which occurred in practice,—the increase of resistance due to wind, to water, to snow, to frost, &c.,—he could not persuade himself, that Engineers would be safe with any system of traction, or upon any gauge, in assuming a lower estimate of resistances, than that which he had pointed out in 1846.

Mr. BRUNEL equally deprecated with Mr. Harding any introduction into the discussion, of the question of the gauges. The only reference to that subject in the Paper, was, that in an attempt on the part of the Author to account for the great differences observed in the results of his experiments, and those calculated from Mr. Harding's formula, he remarked, that a train of 50 tons upon the narrow gauge must be longer than one of the same weight on the broad gauge, and therefore, the resistance of the air upon the sides must be greater. That, surely, was a fact quite independent of the absolute merits of the two systems, for there were, possibly, on the broad gauge, many disadvantages which would more than counterbalance the greater length of train on the narrow gauge. He believed, that the experiments of Mr. Gooch were conducted upon an improved plan, and avoided sources of error which might be imputed to those previously undertaken, and he trusted they would conduce, in their turn, to a better appreciation of the points to be inquired into, and the adoption of the machinery best calculated for arriving at a positive conclusion. But some of the objections made to these experiments were not founded in fact: the carriages were not selected,—means were not taken to reduce as low as possible all causes of resistance,—the portion of line was not chosen on account of its superior condition, nor had it been specially prepared for the experiments. The carriages were taken from those which the superintendent of the station was able to

spare, and as he appeared to be particularly short of stock at the moment, they were by no means perfect: they were hurriedly loaded at once, and taken down the line. For the selection of the portion of railway on which the experiments were made, Mr. Brunel was answerable; they were not made on the portion originally designed by Mr. Gooch, but on a straight level selected by Mr. Brunel himself, only the night before, for the following reasons:—He thought, that to institute any experiments which might be worth recording, the first endeavour should be to make them independent of a variety of interfering causes, which had, hitherto, rendered it impossible to properly compare any two sets of experiments, however carefully they might have been conducted. In practice, no doubt, many sources of resistance would have to be provided against,—dirty rails, windy weather, the engine being out of order, &c.;—these would form, hereafter, legitimate grounds for research, but at present, it was important to ascertain separately, if possible, the amount of the real permanent resistance of trains, and the causes of those resistances, independent of the varying and disturbing causes to which he had alluded. In his opinion, therefore, the experiments should be first made on a level, as it would render it more easy, hereafter, to calculate the exact amount of disturbance occasioned by gradients. For the same reason, the portion selected should be straight; as it was impossible, with the present knowledge on the subject, to predicate the effects of curves,—to say whether they would affect, in a greater, or less degree, a long train, or a short train, a heavy one, or a light one,—it was most desirable, that the experiments should be made on a straight piece of line, so as to obtain data from which the effects of curves might, hereafter, be more accurately deduced. Another condition was, that the portion selected should not be, either in a deep cutting, or on a high embankment, so that the normal action of the wind would be neither diminished, nor increased. Mr. Gooch had selected the ground with reference to this last condition only, and it was in order to carry out the others, that Mr. Brunel pointed out what appeared to him to be a more suitable portion of the railway, and that Mr. Gooch adopted his suggestion. It was, moreover, desirable, that the experiments should be made at a uniform velocity, for the great increase of resistance when getting up speed, and the great diminution when reducing speed, were elements which could not be truly appreciated at present, and materially interfered with the results obtained: to effect this desideratum, it was not only necessary to conduct the experiments over a mile of straight and level way, but to have at both ends of that mile, a sufficient length

of line which would permit of increasing and diminishing the speed without affecting the results. He again distinctly repudiated any idea of his having been influenced in the selection of the ground by a desire of supporting certain particular views: his sole object had been to obtain a correct result, to which no objection might be taken on the ground of interfering causes. He thought, indeed, that had it been possible to have obtained carriages in perfect order, the experiments would have been of still greater value; but as he had before observed, such was not the case, and the mile of line selected, which was the one hundred and fiftieth mile from London, was not in better condition than any other portion of the railway.

Now with regard to the weight of the trains; no one could be justified, in the present day, in making experiments with a train of less than 50 tons weight, exclusive of the engine and tender. He had imagined, that the trains of 50 tons in Mr. Harding's experiments were exclusive of the engine and tender, and he was surprised to learn, that such was not the case; now as the weight of the latter on the South Western and North Western Railways was about 23 tons, the actual weight of the train was only 22 tons, which, he contended, was much inferior to the average weight of ordinary passenger trains on those lines. It must be evident to all, that it would have been a perfect absurdity, to have made the experiments on the Great Western Railway, with a train of only 50 tons weight inclusive of the engine and tender.

Objections had been taken to the results given by the dynamometer, because it was placed at the back of the tender; but there were no means, at present, of measuring the resistance at the front of the engine. Mr. Gooch, moreover, had appended calculations of the different resistances, both with and without the engine and tender, and even if the latter were open to criticism, they did not affect the correctness of the experiments under the conditions in which they were made.

The experiments on inclined planes were originally conducted by Dr. Lardner and others in 1838, at a period when there was no dynamometer in existence, and when, in fact, that was the only method which could be adopted. But the results thus obtained could not be compared with the accurate indications given by the dynamometer. It was perfectly true, that carriages running down inclined planes eventually assumed a uniform velocity, and that the resistance was met by the gravity of the train, but the actual determining cause of this uniform velocity was unknown, and there were many causes of resistance

on inclined planes which did not exist on level ground. This was evident from the fact, that engines really exerted much greater power than they should, according to these experiments; and the resistances thus obtained by Dr. Lardner and Mr. Nicholas Wood, in 1838, were much greater than those found to exist in practice, by Mr. Harding and Mr. Scott Russell, and also by himself on the inclined planes of the Great Western Railway. He was, therefore, entitled to conclude, that the velocity of trains descending inclined planes by their own gravity, was no measure of the real resistances, nor of the traction necessary to propel them at the same velocity by an engine.

Mr. BIDDER was also of opinion, that this question ought to be discussed without reference to the gauges; it was comparatively of little moment whether the resistance were greater on one gauge, or the other, while the great interesting and practical fact of what was the amount and what was the cause of resistance in general, remained undecided. He knew of no method of experimenting which was not liable to great objections, except one, which had been proposed, but unfortunately, had not been carried out: it was, to adopt the atmospheric railway as a dynamometer; this alone would give certain results, and the frontage resistance, which had not yet been ascertained. He readily admitted, therefore, that experiments on inclined planes were not free from objections, yet he thought, that on the whole, they afforded better results than those before the Meeting. He hoped, that the remarks he would offer would enable future experimenters to avoid the errors into which he thought Mr. Gooch had fallen. Allusion was made in the Paper to the preponderance of resistance on the front carriages, in experiments on inclined planes, and it was stated, that the foremost carriages being propelled by the force of gravity acting upon those behind, acquired a certain twist, and thus augmented their friction from other sources than that derived from atmospheric resistance. Mr. Bidder believed, that the resistance arising from the causes alluded to was very slight, but the objection would equally apply to the experiments of Mr. Gooch. In his opinion, the greater resistance in the first carriages could only arise from the frontage pressure of the atmosphere; and although the dynamometer might show the resistance of the train at the back of the tender, it could not give the resistance in front of the engine.

He agreed with Mr. Brunel, that in experiments of this nature, all sources of error should, if possible, be avoided, and that they should, therefore, be made on a straight portion of railway, in the best order, with engines and carriages in the best condition. These

results once accurately obtained, it would be easy, hereafter, to make the necessary corrections for the ever-varying conditions which arose in practice. But he thought, that all the circumstances which could render the experiments valuable, and produce results which could be fully relied on, had not been taken into account. It was evident, that sufficient consideration had not been given to the mechanical points affecting the question, or to the different sources of resistance to which the train was exposed from the atmosphere. The same remark would apply to the anomalous results which had been obtained from the numerous experiments upon bodies floating in water: the causes had all been mixed up together, instead of being separately examined according to the different laws which governed them.

Now with respect to the pressure of the air upon the train; the motion of the wind, unless it were blowing in exactly the same direction as the motion of the train, would, combined with the latter, produce a resultant, making one angle with the frontage, and another angle with the sides of the carriages, and the whole of that pressure must be overcome. The resistance of the frontage was represented by the square of the co-tangent with which the air met the train, and that at the side, by the velocity multiplied by the co-sine of the angle formed by it and the resultant. The Author of the Paper stated, that the air caused a great amount of pressure on the side of the train, and consequent friction on the off-rail, and that the amount of pressure entirely depended on the velocity of the train. Now the only effect of the velocity of the train, was to make the angle at which the air met its course more direct; but whatever was the pressure from the wind, it remained the same, whether the train were in motion, or at rest. It was thus a constant quantity, and, moreover, a very small quantity, unless at high velocities of the wind; and even then, if the wheels were absolutely cylindrical, the pressure on each would be only one-fourth, or one-sixth of that on the carriage, and with conical wheels, it might be reduced to one-thirtieth, or one-fortieth only; at all events, this source of resistance was independent of that of the train.

Supposing an ordinary carriage, 20 feet in length, 7 feet in breadth, and 7 feet in height, to be travelling at the rate of 40 miles per hour, and that the wind was blowing at right angles to the direction in which it was moving, with a velocity of 30 miles per hour, the velocity of the resultant would be 50 miles per hour at an angle of 37°. Supposing the velocity of the wind to be 50 miles per hour, and following the train, the resultant would give, when the train was in full motion, a velocity of 30 miles per hour applied at right

angles to its course. Now although the lateral resistance was due, in both cases, to a velocity of 30 miles per hour, yet in one of the cases, the pressure on the carriages would be 800 lbs.,—a quantity not deduced from theory, but from experiments made with great accuracy by Mr. Rouse. Unless, therefore, the initial velocity of the wind were taken into account, two persons making experiments with the same carriage and on the same line, would have arrived at very anomalous results. The direction only, but not the velocity of the wind was given in the experiments of Mr. Gooch; but in some of them, the angle of the wind was given when the train was in motion, and the pressure of the wind. Combining these data, and the velocity and direction of the train, Mr. Bidder had arrived at the original velocity and direction of the wind, and had found the highest velocity against the train at rest, to be 11½ miles per hour, diminishing to 7 miles per hour. Comparing these results with the description of the wind given by Mr. Gooch, he found, that a velocity of 16 miles per hour was called a "stormy wind," and a velocity of 11½ miles per hour a "strong wind;" this was sufficient to show the little importance that could be attached to such vague designations. The results of the analysis showed, however, that the experiments had been made under favourable circumstances as regarded the wind, and as the largest angle at which it met the train was stated to be 19°, (diminishing to 4°,) it was evident, that no strong side wind was experienced. Mr. Bidder had then endeavoured to ascertain the resistance due to the engine,—taking the weight of the engine and tender in every case at 50 tons,—and the results were also anomalous. In experiment No. 8, at a speed of 20 miles per hour, the resistance to the engine was given as 9·12 lbs. per ton, and that to the train as 9·36 lbs. per ton. In experiment No. 2, where the velocity was 21 miles per hour, the resistance to the engine was described as 6·88 lbs., and that to the train as 8·72 lbs.: the resistance to the engine being about 30 per cent. less, and the resistance to the train only about 7 per cent. less. This was probably due to the greater amount of frontage resistance in the one case, than in the other. In experiment No. 26, the speed being 22 miles per hour, the resistance was 8·26 lbs. per ton; in experiment No. 9, at 42 miles per hour, it was 11 lbs.; and at 44 miles per hour, it reached 15·59 lbs. In experiment No. 21, with a speed of 62 miles, the resistance of the engine was the same as at the speed of 44 miles, whereas the resistance of the train had increased from 17 lbs. to 21½ lbs., or 25 per cent. In experiment No. 12, the speed was 45 miles per hour, the resistance to the

engine 17·71 lbs. per ton, and the resistance to the train 15·14 lbs. Compared with the speed of 62 miles of the preceding experiment, the resistance to the train had greatly increased, whilst the resistance to the engine had actually diminished. Similar anomalies were to be found throughout the whole of the experiments: the resistance of the train appeared to increase generally, but not always, as the speed became greater, but the resistance to the engine followed no law whatever. He had little doubt, that these anomalous results were owing to some circumstances connected with the wind, and he hoped, that in future experiments, its initial velocity would be carefully noted. As no means were adopted for ascertaining the frontage resistance, a great amount of resistance to the train was consequently ignored. He agreed with the Author as to the difficulty in making experiments with the indicator, by which the resistances to the engine were attempted to be shown, and that they could not possess the same weight as those made with the dynamometer; but as it was not possible to apply the latter to the engine, Mr. Bidder knew of no method of ascertaining the resistances which could be relied on, except that of the atmospheric railway.

Mr. Locke, M.P., was still of opinion, notwithstanding the objections made to inclined planes, that it was a method of experimenting less liable to error than that adopted by the Author. It was a well-ascertained fact, that the resistance due to an inclined plane of 1 in 100 was 22 lbs. per ton: a train, therefore, which according to the Author, exhibited a resistance of 21 lbs. per ton while going at the speed of 60 miles per hour, ought to descend an inclined plane of 1 in 100, at that velocity. Now it resulted from his own experiments, and those of others, that the maximum uniform velocity ever attained on such an incline, was 36 miles per hour. The results obtained by the Author were thus in opposition to the laws of gravitation. The subject under discussion was a purely scientific question, of which the solution was equally desirable for, and would be equally advantageous to both gauges.

Mr. Scott Russell was, at first, rather prejudiced against experiments on inclined planes, fearing that the angular motion of the carriages, which could only be prevented by screwing them up tightly, might, on inclines, become so great as to materially interfere with the results. But when he found, that for the same train the resistances were nearly identical, whether it descended an incline by the force of gravity, or was drawn by an engine and the results measured by the dynamometer, he could no longer entertain the same prejudice. In the experiments made under precisely the

same circumstances,—one on the London and Croydon Railway, and the other on the London and Brighton Railway,—the former gave, by the dynamometer, a resistance of 18 lbs. per ton, and the latter gave, by gravity, a resistance of 18·14 lbs. per ton. There were a number of similar facts in Mr. Harding's Tables, which warranted him in assuming the inclined plane to give identical results with those obtained by engine power, and in rejecting the theoretical objections which had been made to that method of experimenting.

Mr. BRUNEL had come to the conclusion, that there must be sources of error in experiments on inclined planes, from observing the difference in the results thus obtained, from those actually afforded by traction. He was able to attain, by gravity only, a much higher velocity down an incline of 1 in 100, than 36 miles per hour. He denied, that a sufficient identity had been established between the two methods: if a series of experiments made by a dynamometer, through a considerable range of velocity, agreed very nearly with a similar series made on an inclined plane, that conclusion might fairly be drawn; the results, however, as a whole, materially differed, and he had, consequently, the right to infer, that the few cases where they agreed, were accidental coincidences.

Mr. LOCKE, M.P., observed, that the higher velocity obtained by Mr. Brunel in descending inclines, might be due to the greater diameter of the wheels of the carriages employed. It was most important, that all the facts, and the circumstances, under which the experiments were made, should be fully stated.

Mr. BRUNEL said, the difference between a wheel 3 feet in diameter, and a wheel 4 feet in diameter, would affect the friction of the axles to the extent of 5 lbs. per ton, at the most, in favour of the latter; but it should also be remembered, the large wheels presented other sources of resistance, which, to some extent, compensated for the difference in the amount of friction.

Mr. D. GOOCH said, that Mr. Harding had seen the dynamometer used on the Great Western Railway, and the experiments which he had made with it fully corroborated those given in the Paper. The argument, that the uniformity in the results obtained by Mr. Gooch was attributable to the effect of oil-cylinders, was untenable, as they had not been used during any of the experiments.

He concurred in the observations of Mr. Bidder, that the direction of the initial velocity of the wind ought to have been more carefully noted, for he must admit, that the wind-gauge was not perfect, and that at high speeds the results were affected by the oscillation of the train and the momentum of the different parts, by tightening which,

the gauge might have been materially improved. He did not, therefore, place much reliance upon it: it was added during the latter part of the experiments in order to give some comparative results as to the resistance of the wind. As to the angle of the wind, there were but few experiments in which it was so great as to strike only a corner of the train. In calculating the resistances, he had made allowances according to the formula given by Mr. Harding and Mr. Scott Russell; in one column, he had added the resistance for that portion of the frontage protected by the tender,—the only portion which ought to be taken into account,—and in another column, he had allowed for the whole of the frontage, which gave an additional increase of about 30 per cent. The difficulty alluded to in the Paper respecting the indicator-cards merely referred to the dangerous position it was necessary to assume, in order to take them, but did not impugn their correctness; the instrument was not affected by the wind. It would be generally admitted, that if the cards agreed with the quantity of water evaporated, there could not be any great error. Assuming the steam used to be of a certain pressure, and that the engine had no more power than what was necessary, the whole power developed was 20 per cent. less in these experiments, than the formula, with all its friction. Objection had been taken to Experiment No. 21, in which it was stated, that the friction was very small; but on reference it would be seen, that the velocity was decreasing, and the resistance of 21½ lbs. per ton was, therefore, less than the proper resistance, for it had been found by experiments, that the friction varied with the power exerted. It was too much to expect, that in experiments of this kind, the results should be perfectly uniform: they were given as recorded by the instrument, in which, as yet, no source of error had been pointed out. No theoretical argument about inclined planes had altered his opinion on that point; in taking a train of 100 tons over the Wotton Bassett incline at 55 miles per hour, he believed it would attain a velocity of 60 miles per hour, even although there might be some increase of resistance from the irregular motion of the carriages.

Mr. BIDDER said, that after the explanations which had been given, he placed still less value on the experiments than he did before. He had taken it for granted, that the results were those actually observed, but he now found, that they were mixed up with calculations modified in a formula, and that the only facts of importance required in analysing the experiments, the direction and velocity of the wind, had been ascertained by an instrument admitted to be very imperfect. During the progress of a train,

the velocity of the wind was continually subject to a variety of disturbing causes: it was, therefore, essential to know its velocity, independent of the motion of the train. He repeated, that all those experiments were made under very favourable circumstances of wind: in no case was there a strong side wind, which might have doubled, or trebled the atmospheric resistance.

Mr. BRUNEL said, that had the resistance shown by the dynamometer been given alone, it might fairly have been urged, that they were incomplete, inasmuch as the atmospheric resistance of the engine was not taken into account; this had, therefore, been added according to the best formula. With repect to the argument about the wind, it was admitted, that the instrument employed to measure its velocity, worked imperfectly; but it should be remembered, that the resistance from that source was included in the other resistances, measured by the dynamometer, and therefore, however desirable it might be to have had more precise details, the absence of them did not invalidate the correctness of the results; nor did he think, that the value of the experiments was at all affected by the fact of the wind having been moderate throughout. Although he had not exactly measured the velocity on descending the Wotton Bassett incline, he had never experienced any perceptible diminution of speed, with a train going at the rate of 60 miles per hour.

Mr. WYNDHAM HARDING observed, that the objections were not directed against the faithfulness of the experiments, but to the use which had been made of them, and the modes of comparison which had been adopted. The resistances given were not the actual resistances per ton as ascertained by experiments, but theoretical resistances, deduced partly from experiment, partly from formulæ. In Experiment No. 39, for instance, the resistance of the train per ton, was, by experiment, 12·35 lbs., but by some manipulation of Mr. Russell's formula, it was reduced in another Table to 11·02 lbs., whereas a right application of the formula would have increased it to 18·46 lbs. He had also to complain of the unfairness of comparing experiments on heavy trains, with experiments on light trains, in order to prove, that there was a greater resistance per cent. on a narrow gauge, than on a broad gauge. The experiments which Mr. Harding had made, were mostly with atmospheric trains, or with trains on inclined planes; they were larger, but not so heavy as those used by Mr. Gooch, and they were not drawn by locomotives, although engines were occasionally introduced, in order to have a heavy object in front.

Mr. BIDDER said, that for the sake of perspicuity, it was very

desirable the experiments should be clear of all extraneous calculations, which had led him into the error of supposing that the figured resistance per ton had been introduced afterwards, instead of being, as he now understood, the actual resistance as measured by the dynamometer. But there were still many examples, which could be adduced, to show that little reliance could be placed on the Tables; in Experiment No. 7, for instance, the friction was stated to be rather more than 3½ lbs. per foot, which, taking the frontage at 60 feet, would give 220 lbs.; yet from the velocity, and the angle at which the engine was moving, it must be evident, that the resistance could not have been less than 700 lbs. He still maintained, that it was most important to record the direction and initial velocity of the wind, and that the indefinite words "strong" and "calm" did not convey any real notion concerning it, and thus materially affected the value of the experiments.

Mr. Locke, M.P., said, that the discussion had proved the impossibility of arriving at any satisfactory conclusions from results derived partly from experiments, and partly from calculation. The Author of the Paper, although opposed to the principle of testing experiments by inclined planes, had given it as his opinion, that, on an incline of 1 in 100, a velocity of 55 miles, or 60 miles per hour could be maintained. This was utterly at variance with Mr. Locke's experience. All experiments on the narrow gauge had proved, that the uniform velocity varied from a minimum of 33 miles to a maximum of 36 miles per hour, and there was no evidence to prove the possibility of attaining a higher velocity by the force of gravity alone.

Mr. D. Gooch said, that in consequence of the opinion which had been expressed, he had since made some experiments on the speed of trains descending the incline planes of the Great Western Railway: for this purpose, carriages were loaded to make up the same train of 50 tons as was used during the dynamometer experiments. In the first two experiments this train was pushed over the top of the bank by an engine behind, and in the others, the engine was sent down in front of and attached to the train. In every case the weather was very unfavourable, on account of a very high wind, blowing at an angle of from 40° to 60° a-head of the train, notwithstanding which, and the fact that the Wotton Bassett incline was in a very exposed situation for such a wind, the following results were obtained.

Experiment No. 1.—Commencing the descent at 45 miles per hour with 50 tons, a gradual increase in the velocity took place, until a uniform velocity of 45·9 miles were obtained, over a distance

of 10-16ths of a mile; the resistance of the wind with the train at rest being, by the wind-gauge, 3 lbs. per square foot, and with the train in motion about 11 lbs. per square foot, and the angle of its direction at rest, about 40°.

Experiment No. 2.—Commencing the descent with the train of 50 tons at 52·3 miles per hour, this speed was maintained at the end of half-a-mile; the resistance of the wind per square foot at rest, by the wind-gauge, was 3·5 lbs., and in motion, about 12 lbs., and the angle of direction at rest was 40° a-head.

Experiment No. 3.—In this experiment the engine and tender were taken down the incline, coupled to the train in front, making the gross weight about 84 tons. The descent commenced at a speed of 50·7 miles per hour, and terminated at the same rate at the end of 10-16ths of a mile; the force of the wind per square foot at rest, being 2 lbs., at an angle of 60° a-head, and in motion, about 11·5 lbs. per square foot.

Experiment No. 4.—The engine and train were taken over the incline as in Experiment No. 3, the gross weight being 84 tons. The speed on commencing the descent was 52·3 miles per hour, and it continued uniform for 10-16ths of a mile; the force of the wind at rest being 2 lbs. per square foot at an angle of 60°, and in motion about 11 lbs. per square foot.

On the previous day two other experiments were made with the same train, but the weather was so stormy, it blowing a very heavy gale of wind, with rain, that they possessed no value as showing the resistance; they were, however, useful in obtaining a diagram of the amount and steadiness of the force exerted by the train in pushing the dynamometer which, in one of the experiments, was placed first, meeting, consequently, all the frontage, and the carriages, weighing 41 tons, acting upon its spring: in the other, the engine and tender were in front of the dynamometer. These diagrams gave the strongest support to the reasons urged in the Paper, against experiments made by gravity. He had there stated, that "the first carriage, whether heavy, or light, if not preceded by a locomotive engine, must, with a head-wind, get the whole resistance due to the frontage. . . . This retarding force has to be overcome by the gravity of the various carriages in the train pushing at the first one, and consequently, pushing each other, and increasing many of the sources of resistance; in fact, exactly reversing the practical working of a railway train. The resistances, measured by this method, must, therefore, be very uncertain, and will, I think, in all cases, exceed the amount due to the same train worked in the usual manner."

Now those diagrams showed, that not only were the last carriages pushing the front ones, but that a most unsteady motion was produced, as compared with the working of a similar train when drawn by an engine in the usual manner; and as this jerking and jolting of a mass weighing 50 tons could not be produced without power, a certain amount of power was thus absorbed instead of assisting in the advance of the train.

In addition to the above experiments, the speed of an ordinary express train weighing about 84 tons, had been carefully observed in descending the Wotton Bassett and the Box inclines, and the speeds were found to be higher than those obtained in the preceding experiments.

Wotton Bassett Incline.				Box Incline.			
No. of Mile Posts.	No. 1. Speed in Miles per Hour.	No. 2. Speed in Miles per Hour.	No. 3. Speed in Miles per Hour.	No. of Mile Posts.	No. 1. Speed in Miles per Hour.	No. 2. Speed in Miles per Hour.	No. 3. Speed in Miles per Hour.
84¼	53	60	53	98	45	..	..
½	45	56	56	¼	43	53	53
¾	45	60	60	½	47	53	53
85							
¼	50	60	56	¾	47	53	54
½	53	60	60	99	Tunnel posts not visible. Average speed 47.	Average speed 53.	Average speed 54.
¾	56	56	60	¼			
86	50	60	60	½			
¼	47	56	60	¾			
½				100			
¾	45	56	64	¼	47	53	54
87	47	56	64	½	47	53	56
	50	60	64	¾	50	53	60
				101	50	53	60
				¼	47	53	60
	Wind very strong ahead, and weather wet.	Wind very strong; not so bad as previous day.	Weather fine and calm.		Weather as in the Wotton Bassett experiment.		
Steam put on at about the 86½ post.				Steam put on at about the 101 post.			

A further check upon the experiments, made with the dynamometer, might be obtained from the consumption of water by the engine, in working the ordinary express trains. The tender held 1,600 gallons of water, and the express was in the constant practice of running the 53 miles to Didcot, without stopping, in forty-eight to fifty minutes, the general consumption of water being 1,500 to 1,550 gallons, and the rise 118 feet: the cylinders were 18 inches in diameter, and the steam was cut off at 15 inches, the full stroke

being 24 inches. In one trip made a fortnight ago, with wheels 8 feet in diameter, when Captain Simmons and several Engineers were present, an average speed of 67 miles per hour was obtained with 1,550 gallons of water, which allowing one-sixth for back pressure, would give 30 lbs. per ton as the resistance of the engine and train weighing 115 tons on the level. The same trip was afterwards run by the same class of engines, in fifty-three to fifty-five minutes, with a consumption of less than 1,500 gallons of water.

							Per Ton.
Other experiments at		52·7	miles	per	hour	showed a resistance of	26·8 lbs.
"	"	57·0	"	"	"	"	26·1
"	"	55·0	"	"	"	"	25·9
"	"	60·0	"	"	"	"	30·5

These results agreed very closely with those measured by the indicator in the cylinder.

During the experiments made by the Gauge Commissioners, it was found and was so stated by Mr. Bidder in his Report, that a train of 60 tons weight was carried at a speed of 54 miles per hour on the Great Western Railway, with a consumption of 232 lbs. of water per mile, whilst on the York and Darlington line the same quantity of water was required to carry 50 tons at 48½ miles per hour; or in other words, the resistances on the Great Western Railway allowed of 20 per cent. more load being carried, at 9 per cent. increase of speed,—a difference corresponding very nearly with that which existed between the experiments upon inclines given in Mr. Harding's Paper and those now laid before the Meeting.

Mr. BIDDER believed, that in every one of the experiments just laid before the Meeting, the results given were less than those of the dynamometer. It was also a remarkable fact, that instead of showing a greater resistance on inclined planes, as had been urged in the Paper, they proved the contrary. He regretted the last observation of Mr. Gooch, as it inevitably introduced the question of the gauges. Mr. Bidder could not, at the moment, recollect the particulars of the experiments alluded to; but his impression was, that with the same load and the same velocity, less steam was used on the York and Darlington line than on the Great Western. The anomaly he had pointed out in Experiment No. 21, in which the resistance of the engine, at a velocity of 62 miles, was the same as that indicated in another experiment, at a velocity of 43 miles, was attempted to be explained by the decreasing velocity of the train. But on examination, he found, that the velocity at starting was 62·5 miles per hour, and at the conclusion of the experiment 61·8

miles, so that the difference, supposing it to be equally diffused over the whole train, would only amount to ½ lb. per ton. A still more remarkable anomaly, which pervaded the experiment, was that in every quarter of a mile, when the velocity of the train was increasing, the dynamometer indicated a decreasing velocity, and vice versâ.

With regard to the velocity on inclined planes, it so happened, that he also had had an opportunity of examining the question on an incline of 1 in 100, with an engine and tender in perfect condition, on one of the days in question, when the weather was described as "stormy, it blowing a very heavy gale of wind," but which he considered nothing more than a stiff breeze. The steam being shut off, the descent was commenced at the rate of 36 miles per hour, which velocity was maintained throughout, except on one portion where there was a curve of the radius of a mile, when the velocity was reduced to 30 miles per hour. From the great discrepancy between this result and that obtained on the Great Western Railway, it was evidently useless to continue to oppose experiments on inclined planes to those made with the dynamometer; the only way, therefore, to settle the question, was to institute a careful series of experiments on the atmospheric line. The Institution had already resolved upon doing so on the Croydon Railway, but unfortunately, before permission had been obtained, the atmospheric system on that line was abandoned. But it was still in use upon the South Devon Railway, and he hoped, that facilities would be accorded for making experiments upon it, under the authority of the Institution.

Mr. BRUNEL would give every aid in his power to individual Members desirous of pursuing these investigations, the results of which might be freely canvassed; but he strongly objected to experiments being made by and under the authority of the Institution, as they would retard further inquiry from the undue weight which would be attached to them. The experiments lately made on the inclined planes of the Great Western Railway confirmed the opinion he had expressed, that the velocity was often much greater than that stated to be the maximum, and fully justified the doubts he had previously expressed, on the value of such experiments. The results obtained were so greatly at variance with those hitherto observed, that there must be some interfering causes which prevented that method being a just measure of the force necessary to impel the train. He was not prepared to admit, that these results were less than those of the dynamometer; but even if such were the case, or had they, indeed, proved less than in other experiments on inclined

planes, it would only be an additional argument in favour of his opinion.

Mr. R. STEPHENSON, M.P., *V.P.*, said, that it was difficult to investigate off-hand the bearings of these experiments: it was, however, clear, that the anticipation of the results being greater than those shown by the dynamometer had not been realised, and that there was an increased velocity in descending the incline. When the engine and tender were coupled to the train, the initial speed was maintained; but as the addition of an engine necessarily increased the resistance per ton of the whole train, it was natural to expect, that retardation would take place sooner with a mixed train, than one composed of carriages alone. It would result, therefore, from these experiments, that with an ordinary train, there would be an acceleration of speed on descending an incline of 1 in 100 at an initial velocity of 50 miles per hour, whilst it was already proved, that there would be no acceleration when the initial velocity was 36 miles per hour. Such, at present, was the state of that part of the question.

With regard to the discrepancies in the original experiments and those of Mr. Harding, he would observe, that uniform results could never be expected, when experiments were made by individuals under such a variety of circumstances. But in averaging the results of Mr. Gooch's Tables and comparing them with Mr. Harding's formula and the experiments originally instituted, on an inclined plane, by the British Association, he thought, that some approximation might be made to the actual resistance. From the experiments of Mr. Gooch, it appeared, that the formula gave too great a resistance at low speeds, and the experiments of the British Association also showed rather less resistance than that given by the formula. At high speeds, although an increased acceleration was attended with a greater resistance than that given by the formula, yet as soon as the velocity diminished, the resistance was less than by the formula; so that, in reality, the formula very nearly approximated to the average results of the experiments at high speeds. The formula, however, would not equally apply to all lengths and all descriptions of trains. It was, no doubt, convenient to represent the resistance by so many pounds per ton, and to adopt this as a unit, or common measure; but it should be remembered, that the largest portion of the resistance being due to the air, it would be much greater with a bulk of low specific gravity than for a mass of iron.

Again: Mr. Harding's experiments were made with trains under 70 tons weight, and with engines and tenders of which the weight

did not probably exceed 25 tons, whereas Mr. Gooch's experiments were made with trains of 150 tons, and with engines and tenders of 40 tons, or 50 tons: now it was evident, that until the resistance per ton of each component part of the train was ascertained, the results could never agree.

From these and other considerations, he thought that no practical results could ever be attained, unless the experiments were undertaken by such an authority as the Institution, which could establish proper conditions, and thus divest the question of the extraneous and difficult complications always attendant upon individual and isolated experiments.

He could not understand the objections made to experiments on inclined planes by the force of gravity, which was a simple and well-ascertained force which could easily be measured. It had been stated, that if loaded waggons were placed in the middle, or behind the train, they jostled and pushed the carriages in front, so much so as to double, or even treble the resistance observed in the experiments of Mr. Harding and those of the British Association. But if this was an objection to experiments on inclined planes, it equally applied to experiments on a level, for on almost all railways, the carriages were driven forward by a centre rod passing through them, and the intermediate carriages were, consequently, impelled by the last carriage in the train. He had frequently observed, when riding in the coupé of a railway carriage, that the buffers were very often compressed, whilst those of the preceding carriage were expanded. He could not believe, that this fact operated to any injurious extent, and he felt assured, that whatever errors might be imputed to experiments on inclined planes, they were the best which had been hitherto obtained, and that it was a method of measuring resistances greatly superior to that of placing a dynamometer between the engine and tender, and then estimating the resistance of the former by some empirical formula.

Mr. WYNDHAM HARDING said, that whatever might be the merits, or demerits of the formula, which had been so often referred to under his name, its introduction was due not to him but to Mr. Scott Russell, and he had only made use of it, as he stated in his Paper,* "simply as an empirical formula, in order to see how it agrees with the facts furnished by experiments, made by different persons at different times." It appeared to him to indicate pretty accurately the results of the numerous experiments he then laid before the Institution; and even when stretched from 64 tons

* *Vide* Minutes of Proceedings Inst. C. E., 1846, vol. v., p. 405.

to 180 tons, it approached as closely as might fairly have been expected, to the total resistances obtained by Mr. Gooch from the indicator. With regard to the more recent experiments laid before the Meeting; similar experiments had been made by himself upon an incline of 1 in 74, on the gauge of 7 feet, but over a greater distance: a reference to his Paper* would show, that "the engine pushed the carriage over the top of the incline at 40 miles per hour," with results very different to those obtained by Mr. Gooch, and more to be relied on, as the experiments were made over a distance of 2¾ miles, instead of 10-16ths of a mile only. It was important, however, to note the resistances which had been just given: instead of a passenger train at a velocity of 60 miles per hour, showing a resistance of only 17 lbs., or 18 lbs. per ton, as had been asserted before the Gauge Commissioners, the resistance, (although measured by the evaporation of water, a method of which Mr. Harding did not approve,) was found to be 26·8 lbs. per ton at 52·7 miles per hour, and at 60 miles per hour, 30 lbs. per ton, which closely approximated to the estimate given by Mr. Harding in 1846.

There were many radical objections to the comparisons attempted to be instituted by Mr. Gooch. It was, evidently, fallacious to compare the resistance per ton of trains weighing from 100 tons to 150 tons with the resistance per ton of trains weighing from 30 tons to 64 tons; and to compare the resistance measured behind the engine, after it had overcome that of the air, with the resistance of a whole train. The rest of the Tables were compounded of experiment and assumption, and were not to be depended upon. For instance, in Experiment No. 28, the resistance by the dynamometer, at 56 miles per hour, was stated to be 19·4 lbs. per ton, and the frontage resistance was put down at 1½ lb. per ton, giving the total resistance as 21 lbs. per ton: whereas the addition for frontage, according to the basis adopted in other calculations, should have been 5½ lbs., this making the total resistance 24¾ lbs. per ton. Again, in Experiment No. 20, only 4½ lbs. per ton were added for the frontage resistance, instead of 9 lbs per ton. These differences materially affected the rate of per centage, when the quantities operated on were so small.

Attempts were also made, in some of the Tables, to explain certain anomalous results by reference to the difference of gauge, whereas they probably depended on collateral circumstances, which had not been carefully examined;—the direction and force of the wind, for example, were continually being modified by the velocity and direc-

* *Vide* Minutes of Proceedings Inst. C. E., 1846, vol. v., p. 382.

tion of the train, and thus materially affected the amount of frontage resistance. The oblique force of the wind was also modified by the well-ascertained fact of the existence of two parallel columns of air, along the sides of a train in motion. Recollecting, moreover, that the frontage pressure was a direct pressure, such as would be produced by opening a door against the wind, but that the pressure against the sides was an indirect pressure, it would be seen, that there were elements to be taken into account which required delicate research, and could not be lightly disposed of by a reference to the gauge: moreover, if there was one fact more clearly established than another in the working of the gauges, it was, that in proportion to a given number of passengers, or goods, the displacement, the size, the bulk, and the weight were much less on a narrow gauge than on a broad gauge.

Mr. LOCKE, M.P., attached much greater importance to the recent experiments on inclined planes, than to the others, as they were founded upon an immutable law of nature, which must, necessarily, give results more to be depended on, than those obtained by machines, however delicately constructed. He felt, however, the full force of the objection, that the results given to trains of 150 tons weight could not be fairly compared with those of a train of only 50 tons, and in order to arrive at any satisfactory conclusion, it was essential, that the experiments should be made under similar circumstances, with the same weight and description of train, and with wheels of the same size. The direction of such experiments by the Institution, *ex officio*, was open to grave objections, but it would not be difficult for individual Members to agree upon the proper conditions to be observed, in order to attain so desirable an object, as a correct basis on which all calculations might be made, irrespective of the gauge. He wished to know whether the inclined plane was longer than the 10-16ths of a mile, and if so, whether the experiments were continued beyond, and with what results.

Captain W. S. MOORSOM said, that the experiments on inclined planes were not satisfactory, as true results were not to be obtained until a period later than that at which the experiments were ended: 10-16ths of a mile could hardly be considered otherwise than as the commencement of an incline. There were many inclines of upwards of 2 miles in length, on which the experiment might be made, both on the broad gauge, and on the narrow gauge, and also on the Irish, or intermediate gauge. On the Waterford and Kilkenny Railway, there was an incline of 1 in 100, upwards of 2 miles in length, on which he promised to institute experiments, and lay the results

before the Institution. It was, certainly, most important to ascertain whether trains could be run with the low pressure which the experiments of Mr. Gooch seemed to indicate.

Mr. D. Gooch said, that the inclined plane was longer, but the gradient was easier. The experiments in the Box Tunnel were made on a length of 2 miles, and in some of them, the velocity was actually increasing at the conclusion of the observations.

Mr. Brunel said, that two of the experiments only were made with an engine in front, and it was so placed in order to assimilate them to ordinary practice. The observations were taken at every sixteenth of a mile, the velocity being mechanically measured by an instrument, which method gave, in his opinion, higher value to the experiments, and results thus ascertained were more to be depended upon, than bare observations, when made over a greater length. He could not admit the validity of the objection, that the trains experimented on were from 100 tons to 150 tons weight, for, deducting the engine and tender, they were in reality trains of from 50 tons to 100 tons, and these were the weights used in practice. The question was to ascertain the power required to move the train, independent of that absorbed in moving the engine itself. The experiments were avowedly made by measuring the force of traction by a dynamometer, which must, necessarily, be placed between the engine and train, and did not, therefore, include the atmospheric resistance of the frontage, which was accordingly added from the best formula which could be obtained. If those calculations were incorrect, they could be amended; but the results given by the dynamometer could not be impeached, as they were as equally due to a law of nature, as those obtained from the inclined plane.

Mr. Scott Russell said, that on the narrow gauge it was useless to make further experiments on inclines of 1 in 100, since it was abundantly proved, that they could be attended with no other result than a uniform velocity of about 36 miles per hour. What was now wanted, was to ascertain the resistance at higher velocities, and therefore, all future experiments should be made on steeper inclines. On the broad gauge, an accurate series of experiments was to be desired, not only on steep inclines, but also on inclines of 1 in 100, in order that the results might be compared with those obtained on the narrow gauge. He thought the most favourable manner of making the experiments was to employ trains, weighing not less than 50 tons, and to place the engine in front, with the steam shut off, but with the valve in the easiest position for the engine. From his own experience on inclines of 1 in 100, he

had found, that the engine travelled more freely at 28 miles per hour, and he inferred, that below that speed, the friction of the engine was greater than the resistance of a train of equal weight, and at a higher speed, less. This would explain the uneasy motion of trains descending an incline of 1 in 100, at 36 miles per hour, for the engine would, to a certain extent, be pushed forward by the train; but whatever might be the real cause, it was an undoubted fact, that the motion of a train descending an incline by the force of gravity alone, was much easier than that of a train propelled at the rate of 36 miles per hour, even on a level. He could not understand the objection to the employment of gravity as a dynamometric measure, nor had he ever found any difference between the dynamometric results of a train drawn by an engine, or a train descending an incline by its own gravity, at the same velocity.

As to the formula so often referred to, he had deduced it from a great number of experiments by the best modes of analysis, and on comparing it with the experiments of Mr. Gooch, he still thought it correct. He started with the generally-received allowance of 7½ lbs., as a constant quantity, for axle friction, which he accordingly deducted from all the experiments. For head resistance, he used a formula deduced from his own experiments, as preferable to the received formula, which was founded on Smeaton's experiments upon windmills and other sources inapplicable to railway trains. Examining the true measure in air and in water, not of a thin disk, but of a long box, he found, that it exactly coincided with the well-known formula, that the resistance on each surface ought to be increased by the pressure of a column of fluid of a height equal to that which, by gravity, would produce the velocity of motion. That being also deducted from the experiments, there remained ¼ of a lb. per ton, per mile, per hour, which constituted the empirical part of his formula: but he believed he had arrived at an approximation to a law, which was comprehensible, easily expressed, and represented the facts. This residuum, varying with the velocity and weight of the train, was probably made up of the propagation of waves through the earth, and of concussions arising from inequalities of the road, whence it might fairly be expected, that these disturbing influences would be diminished by increasing the diameter of the wheels, and thus that with wheels 4 feet in diameter instead of 3 feet, this quantity might be reduced from ¼ of a lb., perhaps, to ⅛ of a lb. per ton, which would evidently lower the "line of resistance" given by the formula. As a means of accelerating speed, large wheels were, in his opinion, decidedly superior to small wheels.

He could hardly exaggerate the importance of this question, and he thought it was the bounden duty of every member of the profession to do all in his power to ascertain the absolute truth, irrespective of its bearing upon the question of the gauges. It was consolatory to know, that the continued researches and experiments of Engineers had succeeded in effacing many differences of opinion which formerly existed, and he did not doubt, that such also would be the result of careful investigation and experiments upon the resistances to railway trains at different velocities.

Mr. Locke, M.P., had under his charge some inclines varying from 1 in 100 to 1 in 75, and from 4 miles to 10 miles in length; and he promised to institute on them every possible method of experiment by which the truth might be ascertained, and to lay the results before the Institution.

Mr. Crampton, alluding to the statement in the Paper, that the experiments proved short trucks with the wheels close together to require greater power than long carriages, said he was of the same opinion, and he believed, that the small distance between the wheels on narrow-gauge lines, occasioned a great loss of power. There was always a certain amount of play between the flanges of the wheels; and the greater the distance between the wheels, the less abruptly would they strike the rails. To this there was, of course, a limit, which would be best determined by reference to the chord line formed by the carriages in passing round a curve 10 chains in radius.

Mr. Charles Fox observed, it was important that the carriages employed in different experiments, should be similar in length, breadth, and height, and that the wheels and axles should be of the same weight. A carriage with less weight in the body, and more in the wheels and axles, would descend an inclined plane with greater velocity than a carriage under the opposite conditions, on account of the additional weight of the wheels, which would be rolling on the rails and not rubbing on the journals, and the oscillation would not produce the same amount of friction. In order to insure correct results, the carriages should be made as simple as possible; and the axles should be so constructed as to admit of different wheels being applied to suit the various gauges.

Mr. R. Stephenson, M.P., *V.P.*, called the attention of the meeting to a copy of the Paper which had been inserted in the "Morning Herald." It was there distinctly treated as a question of gauge, one column being headed "Increased resistances per ton, on narrow-gauge trains, as compared with the broad gauge, assuming the broad-gauge formula is correct." He could not

reconcile this with the assurances which had been given, that the Paper had been compiled solely with reference to the scientific question of resistances, and not, as had been alleged, to further any particular views.

Mr. BIDDER said the Paper had for object either to give the real resistances, or to furnish facts from which those resistances might be deduced. He had already pointed out certain defects; the frontage resistances, for example. It was said, that they were not interfered with, and that all the angles were taken from the corner of the fire-box; but the frontage resistances were so mixed up with the resistances to the engine, that it was impossible to arrive at any accurate conclusions. The indicator-cards were relied on, but he had shown how anomalous were the results: at 20 miles per hour, the resistance of the engine varied from 13 lbs. to 18 lbs. per ton; at 45 miles an hour, it was 45 lbs. per ton; and at 61 miles per hour, it fell to 24 lbs. per ton. This difference was attempted to be accounted for by the variations in velocity during the last experiment, but he had proved, that this would not amount to more than ½ a lb. per ton. The friction on the sides was stated to have been considered, but the amount of this depended on the initial velocity and direction of the wind, which had not been correctly given. One portion of the Paper had for its object, to destroy faith in former experiments on inclined planes, but since the opening of the discussion, the Author had himself made experiments by that method and the results controverted the reasoning in the Paper. The whole question was thus left in a most unsatisfactory state. The gauge experiments made in 1846 were then quoted, to show that, by Mr. Bidder's own admission, the resistance was 20 per cent. less on the broad gauge than on the narrow gauge: but on reference to the figures, it would be seen, that he had never advanced such an opinion. The Report of the Gauge Commissioners was then published, and immediately afterwards the "Morning Herald" inserted the Paper as conclusive of the superiority of the broad gauge, notwithstanding the assurances given, that the subject had been considered quite independent of the question of the gauges. He did not think, that this Institution should have been made use of for such a purpose; but it was evident, that the discussion must now be regarded, as a discussion upon the respective merits of the gauges. As such, he gave his adhesion to the experiments of Mr. Harding and Mr. Scott Russell, and to the formula they had adopted, with some slight modification, on account of the greater weight of the carriages now used, in consequence of the increased speed. Since the opening of the

Birmingham Railway and the Grand Junction Railway, the weight of the carriages had increased 60 per cent.: the resistance per ton was, therefore, less, although the resistance per carriage was greater. But, taking the resistance at 50 miles per hour, to be, as represented by Mr. Gooch, 22 lbs. per ton for carriages weighing 10 tons each, the result would be 26 lbs. per ton for carriages weighing only 8½ tons each. It was much to be regretted, that facilities would not be accorded to the Institution for making experiments on the South Devon Atmospheric Railway: the refusal did not show real confidence among the partisans of the broad gauge, in its alleged superiority on the score of diminished resistances.

Mr. Scott Russell wished again to call attention to the practical application of the experiments brought forward by Mr. Harding and himself. There were certain resistances which varied as the square of the velocity, depending on the frontage of the train and the resistance of the atmosphere: there was no hope of diminishing these, as in all the forms proposed to be given to the front of a train, the length modified was, necessarily, so small, as not to be of the slightest practical value. Nor was there any material advantage to be gained from improvements in the next element, the axle friction, which increased in the same ratio as the velocity, for supposing it was capable of being reduced to 3 lbs., or 4 lbs. per ton, the difference would be a very small proportion of the whole resistances of the train. But there was a large residuum, varying with the velocity, and amounting, at 40 miles per hour, to 20 lbs. per ton, which was probably due to the imperfection of the carriages, to irregularity in the motion of the propelling power, to concussions of the ground, and to bad condition of the railway. Now this residuum was capable of being diminished, and, in fact, had been diminished in the express trains, on all the first-class railways in the kingdom, and he had little doubt, that if experiments were made with the newest and best class of carriages now in use, it would be found, that the amount of that element in the formula ought to be considerably reduced.

Mr. Wyndham Harding said, that from the Report of the Gauge Commissioners which had just appeared, there was a prospect of the distance between London and Edinburgh being materially reduced by Act of Parliament, for in one of the Tables of the calculation of speed, in which great stress was laid on the comparative merits of the two gauges, 50 miles of the distance were entirely omitted. Again: the South Western trains from London to Southampton were made to run one mile per hour slower than the Great Western trains from London to Exeter, whereas their speed was one

mile and a half per hour faster. These were specimens of the many gross errors to be found in the Report, three parts of which were occupied with the experiments of Mr. Gooch, regarded solely with reference to the question of gauge. Now in considering that question, he would first call attention to the fact, that in many respects, the two gauges were very similar; the rails were of the same material and form, and the wheels of the same construction and nearly of the same diameter. On the Great Western Railway, the wheels were, generally, 4 feet in diameter, but some of them were only 3 feet; and on the Bristol and Gloucester Railway, also a broad-gauge line, the wheels were 3 feet 6 inches in diameter. On the narrow-gauge lines, the wheels were never less than 3 feet in diameter, and some measured as much as 3 feet 9 inches. There was, therefore, little difference in that respect, although the broad gauge necessitating longer, and consequently, thicker axles, seemed to require also larger wheels, in order to overcome the axle friction, which must be greater than in the narrow gauge, in consequence of the greater diameter of the journals. The mode of hanging the carriages on springs was the same on both gauges, as were also the general arrangements. But there was one point on which they necessarily differed, in the breadth of the carriages and trucks, and consequently in their length also, for the form of the horse-boxes on the broad gauge, in which the length had not been proportioned to the breadth, could never be given to passenger carriages. The dimensions and form of the carriages being thus necessarily different, it was easy to prove, from the figures furnished to the Gauge Commissioners by Mr. Gooch himself, how materially that circumstance affected the resistances. First, as to passenger trains: on the Great Western Railway there was an average of forty passengers per train, with a weight of 67 tons, or 60 per cent. heavier than the passenger trains of the London and Birmingham, and the South Western lines, with as many, or more passengers per train. Such was the result as regarded the dead weight: he would now compare the bulk and displacement. The average weight of the Great Western trains was 67 tons, that of the Grand Junction trains was 43 tons: deducting in each case 5 tons for the passengers, the weight would be, respectively, 62 tons and 38 tons. According to the evidence of Mr. Gooch before the Gauge Commissioners, the average length of the Great Western carriages was 26 feet, and the width was 9 feet: on the Grand Junction Railway, the average length was 14 feet, and the width was 6 feet 6 inches. The 62 tons of the Great Western Railway would represent nine carriages, or a length of 234 feet, whilst the 38 tons of the Grand Junction would

require ten carriages, or a length of 140 feet: a Great Western train was thus 67 per cent. larger than a Grand Junction train, and the bulk was, respectively, 20,007 feet, and 8,563 feet, or 140 per cent. greater. The carriages on the South Western Railway were the largest in use on the narrow gauge, and calculated on the same principle, the length of a South Western train was 213 feet: the Great Western trains were thus 10 per cent. longer, the bulk 40 per cent. greater, and the weight 50 per cent. more. Secondly, as to goods trains, the experiments on which were repeatedly and carefully made at the break of gauge at Gloucester, where, from his position as superintendent, he had the best opportunities of judging the respective value of the two systems. In one of the experiments, 219 tons net, which occupied, on the broad gauge, forty-eight waggons weighing 228 tons, were transferred on the narrow gauge, to sixty-five waggons weighing 169 tons: the dead weight, therefore, was 35 per cent. greater on the former. The area, or the width by the length, was 7,000 feet on the broad gauge, against 5,800 feet on the narrow gauge, the displacement was thus 22 per cent. more. These facts and figures were, he thought, conclusive on the subject of resistances: but they had other bearings, such as the increased cost of engine power on the broad gauge, and the greater difficulty of moving the trucks which, in one case, had occasioned a disastrous accident.

Mr. F. BRAITHWAITE hoped, that the subject would not be treated as a mere question of gauge to the exclusion of a much more important point,—the determination of the true resistances under the circumstances mentioned in the Paper. On the last occasion when this subject was discussed, he remarked, that it was almost impossible to establish any formula which should be sufficiently comprehensive to meet all cases, as the circumstances varied so considerably, and combined so many different elements of resistance. There were many points, however, on which accurate conclusions might be hoped for, as for example, the form of wheels which presented the least amount of resistance. In some experiments instituted on an incline on the Shields Railway, Mr. Nicholson had observed, that when the engine was in front of the train, the carriages appeared to push against the engine, and when the engine was placed behind, the carriages dragged it forward. He thought, that this important question should not be left any longer without solution, and that the Institution should at once take steps for bringing it to some definite issue.

Mr. R. STEPHENSON, M.P., *V.P.*, agreed in the policy of separating the question of resistances from that of the gauges, but

under the circumstances of the case, it was impossible to avoid a discussion upon the comparative merits of the two systems. Experiments had been made, in the first place, on inclined planes of narrow-gauge lines, to ascertain the resistances from the force of gravity, a method which he believed to be unexceptionable. Other experiments were then made on the broad gauge by means of a dynamometer: the resistances were found to be much less than those observed by the British Association, and objection was taken to the experiments on inclined planes as involving contingencies which tended to over-rate the resistances. A third series of experiments had been since made on broad-gauge inclines, and the resistances, instead of being greater, were found to be still less than those encountered on a level. These differences were attributed to the great superiority of the broad gauge; and the accuracy of the formula hitherto acted upon by Engineers, as nearly approximating to the results of experiments at low speeds, (although it was admitted, that for high speeds, some correction was necessary,) was denied: it became, therefore, imperative to investigate the question of gauge. It was impossible to believe, that a difference of 2 feet could affect the mechanical question of resistances. It would be advisable, that the partisans of both gauges should be present at all future experiments, and a near approximation to the truth might soon be arrived at, from the expenditure of water on the different gauges, which afforded a fair criterion of the power employed to convey a given weight over a certain distance, at any speed which might be agreed upon.

Mr. HAWKSHAW observed, that as the object of railways was the conveyance of passengers and goods at the least cost, consistent with a given rate of speed, the important point to be ascertained was the resistance per passenger and per ton, and that railway would be considered the best which was able to carry passengers and goods the most comfortably and quickly, at the least expense. The observations of Mr. Harding were, therefore, most valuable as elucidating the commercial part of the question.

Mr. THOMSON said, that although the difference of gauge materially affected the commercial question of cost, it could have no influence on the scientific question of resistances. He regretted, therefore, that it had been introduced into the discussion, for it might lead to a belief, that the laws of resistances were not equally applicable to both gauges.

Mr. R. STEPHENSON, M.P., *V.P.*, admitted, that the two questions, although equally important, were perfectly distinct, and should, if possible, not be mixed up together. The abstract question

of resistances did not involve a consideration of the relative merits of the two gauges, but the subject had been forced upon the notice of the Institution, by the extraordinary differences in the results of the experiments, and the only way in which that difficulty could be met was to institute other experiments on both gauges, under the joint superintendence of the advocates of both systems.

Mr. WYNDHAM HARDING reminded the Members, that two years ago when the contest of the gauges was at its height, he had presented to the Institution a Paper on Resistances, entirely devoid of any allusion to the merits of the gauges.* He would have desired, if it had been possible, to have followed the same course on this occasion, but as the recent experiments had been presented to an incompetent tribunal, not under their scientific aspect, but under the semblance of realized economy, it became absolutely necessary to point out the fallacies involved in that treatment of the question.

Mr. HAWKSHAW could not see the utility of separating abstract questions of resistances from the practical application of the results, which was, or should be, the ulterior object of all research. Theoretical railway trains might be arranged and certain resistances found, but the conclusions would be worthless, unless account were taken of the useful load which could be thus conveyed, and the consequent cost of transport.

Mr. SCOTT RUSSELL thought one conclusion had been arrived at,—that new experiments must be made on an extended scale, and that they should set forth the amount of useful weight as well as the amount of dead weight conveyed. A general disposition had been evinced to aid the Institution in every possible way in the prosecution of these experiments: he hoped, therefore, that a committee would be forthwith appointed, to conduct them, and that all who were interested in the subject, would point out to its Members the points, which, in their opinion, demanded investigation.

May 2, 1848.

JOSHUA FIELD, President, in the Chair.

The following Candidates were balloted for and duly elected:—John Ward, Richard Vardon, John Sutherland Valentine, Grant Samuel Dalrymple, and Charles Greaves, as Members; Thomas Talbot Bury, and John Watson, as Associates.

---

* *Vide* Minutes of Proceedings Inst. C.E., 1846, vol. v., pp. 369—411.

No. 786.—"Observations on the causes that are in constant operation tending to alter the Outline of the English Coast, to affect the Entrances of the Rivers and Harbours, and to form Shoals and Deeps in the bed of the Sea." * By John Thornhill Harrison, M. Inst. C.E.

In presenting this Paper to the Institution of Civil Engineers, it is hoped, that the discussion upon it will be serviceable, in aiding those who may hereafter undertake the further investigation of the subject, for the purpose of discovering means of counteracting the prejudicial effects which are felt to be in operation, or of encouraging and promoting those of an opposite character. It can hardly be expected, that much novel information will be brought forward; but it is hoped, that the interest which must attend the consideration of almost any observations on such a matter, will be admitted as a sufficient excuse for the introduction of this Paper before the Members of the Institution, among whom there are many so well acquainted with the operations treated of, that any erroneous views which may have been advanced will be readily detected; at the same time, it will be very satisfactory to find, that some of the opinions advanced are coincided in by such competent judges.

It has been frequently remarked by those whose attention has been drawn to the subject, that many harbours are in a progressive state of deterioration. The local histories of the most important maritime towns, the evidence given before the Tidal Harbour and Harbour of Refuge Commissioners, and the observations of Mr. Lyell, in his "Principles of Geology," all support the opinion, and combine to impress the mind with the importance of an inquiry into its causes. Much information has been derived from the following works, all of which will be found to repay a careful study:—

The standard works of Sir Henry De la Bèche and Mr. Lyell.

Professors Airy and Whewell, and Mr. J. Scott Russell's excellent Papers on Tides and Waves, which are of the greatest utility in explaining the facts derived from other sources.

Mr. Stevenson's Paper on the bed of the German Ocean, and Mr. Palmer's on Shingle Beaches,—which are both very interesting.

The able Reports of the Tidal Harbour and Harbour of Refuge Commissioners, which, with the evidence taken by the Committee and appended to the Reports, are most valuable.

The Piloting Directions for the coasts round England, the facts contained in which, together with the soundings and other informa-

* The length of this Paper caused the reading of it to be extended over two evenings, but the whole is printed together.

tion given on the accompanying Charts, form a rich mine whence much practical information may be derived.

The observations made by Mr. Le Gallais, for Mr. Brunel, on the beaches in the West Bay, also afford much interesting data.

Maps, or charts of the coast representing the configuration of the island in days gone by, are, so far as they may be depended upon, invaluable, in enabling a comparison to be instituted between the present and the former outlines of the coast,—to infer thence, the causes that have produced the changes,—and when such changes do not exist, to test, by the application of the facts thus disclosed, the hypotheses formed to explain their occurrence elsewhere.

On examining in this field the operations of nature, the following causes are found to be more, or less constantly acting, and with a greater, or less degree of intensity:—

The fresh waters running down streams and rivers, carrying with them varying quantities of earthy matter.

The tidal waters running alternately into and out of rivers and estuaries.

The tidal waves in the open sea.

The waves of the sea, when agitated by the wind, acting upon the coasts.

Springs and the influence of the atmospheric changes.

To investigate fully these several subjects would be most interesting and useful; but the following remarks suffice to elucidate the effects in the particular sphere of their operations, to which these observations are intended to apply.

The origin and progress of rivers has been compared by Pliny to the life of man.* "Its beginnings are insignificant and its infancy is frivolous, it plays among the flowers of a meadow, it waters a garden, or turns a mill. Gathering strength in its youth, it becomes wild and impetuous. Impatient of the restraints which it still meets with in the hollows among the mountains, it is restless and fretful, quick in its turning and unsteady in its course. Now, it is a roaring cataract, tearing up and overturning whatever opposes its progress, as it shoots headlong down from a rock; then, it becomes a sullen and gloomy pool, buried in the bottom of a glen. Recovering breath by repose, it again dashes along, till, tired of uproar and mischief, it quits all that it has swept along, and leaves the opening of the valley strewed with the rejected waste. Now quitting its retirement it comes abroad into the world, journeying with more

* *Vide* Encyclopædia of Geography. By Hugh Murray, F.R.S.E. Book ii. page 195. London, 1834.

prudence and discretion, through cultivated fields, yielding to circumstances and winding round what would trouble it to overwhelm, or remove. It passes through the populous cities, and all the busy haunts of men, tendering its services on every side, and becomes the support and ornament of the country. Increased by numerous alliances, and advanced in its course, it becomes grave and stately in its motions, loves peace and quiet, and, in majestic silence, rolls on its mighty waters, till it is laid to rest in the vast abyss."

A river in such a course, must necessarily bring down with it a large quantity of earthy and other matter, and it becomes a most important engineering question, where this is deposited. The answer is, that the circumstances are ever varying, and that the matter would be carried onward, so long as the water had the requisite velocity for its transport. The stream, at some seasons, would be insufficient to carry it beyond a certain point, where, however, it would only find a temporary rest; the floods, at another time, urging it forward to a greater distance, it is only in the "vast abyss" into which the river discharges itself, that its permanent resting-place is found. A lake, as is shown by Lyell, occasionally intervenes, which being filled up in the course of time, by the matter carried into it, leaves only a channel through which the river at last passes over the former surface of the lake, carrying with it the detritus to a more distant place of rest.

Some rivers discharge themselves immediately into the sea, forming deltas at their mouths; but in many British rivers, the discharge is into estuaries, and it is to the consideration of the latter, that these observations are particularly confined, although few among them are sufficiently large to enable them to form sea deltas. The history of deltas shows, that there exists a constant contest between the productive tendency of the rivers, and the destructive action of the sea; on insular shores, the latter would always have the mastery, dispersing over its bed, or casting upon its beach the material carried into it. In the formation of any delta, whether in a lake, an estuary, or the sea, the heavier particles are deposited first; the distance to which the others are carried depending, *cæteris paribus*, on their size and specific gravity, and on the opportunities afforded by eddies for their escape into still water. The whole of the detritus so deposited, is not necessarily beyond the reach of disturbing forces; the tidal waters, and wind-waves, both coming into action, to change the position of some of it.

Before proceeding to the consideration of the action of the tide and wind-waves on the coasts, attention should be directed to the

nature and action of waves generally. The following particulars, taken from Professor Airy's and Mr. J. Scott Russell's Papers on Waves, will serve to introduce and explain what will be stated on the different subjects of the inquiry.

There are two orders of waves, of distinct and very decidedly different characters:—the wave of translation, or of the first order, and the undulating wave, or of the second order. The distinctive characters of the waves of the first order which are referred to in this Paper are,—

1st. That the motion of the water in transmitting the wave is entirely in the direction of the wave: hence its name.

2nd. That the motion of the water is the same at the bottom, as it is at the surface.

3rd. That the velocity of the wave is the same as a body would acquire in falling through a space, equal to half the depth of the water, from the summit of the wave.

The distinctive characters of the waves of the second order which are referred to are,—

1st. That the motion of the water is alternately opposed to, and in the direction of, the wave's motion; the water during the transmission of the wave, alternately flowing on both sides, towards and from a point, thus forming the undulations; whence its name.

2nd. That the greatest velocity of the water is at the highest and lowest parts of the wave, being zero at half the whole height of the wave.

3rd. That when the length of the wave is not greater than the depth of the water, the velocity of the wave depends, (sensibly,) only on its length, and is proportional to the square root of its length; but when the length of the wave is not less than a thousand times the depth of the water, the velocity of the wave depends, (sensibly,) only on the depth, and is proportional to the square root of the depth: it is, in fact, the same as the velocity which a free body would acquire, by falling from rest, under the action of gravity, through a height, equal to half the depth of the water.

4th. When the depth is great, compared with the length of the wave, as in ordinary wind-waves, the motion of the water at any great depth below the surface is wholly insignificant, in comparison with that at the surface. As the depth below the surface proceeds in arithmetical progression, the motion of the water diminishes in geometrical pro-

gression, and at a depth equal to the length of the wave, the motion is diminished to $\frac{1}{535\cdot4}$ of that at the surface.

5th. The greatest horizontal motion of any particle is equal to its greatest vertical motion, except for those particles very near the bottom, where the whole motion is insensible.

6th. When the length of the wave is great, in comparison with the depth of the water, (as in the case of tide-waves,) the horizontal motion is sensibly the same from the surface to the bottom, and the vertical motion, for different particles, varies in the same proportion as their height above the bottom.

7th. On the same supposition, the vertical motion of the superficial particles is very much less than their horizontal motion: the proportion of the vertical motion of the superficial particles to the horizontal motion $= 6\cdot2832 \times \frac{\kappa}{\lambda}$; λ being the length of the wave, and κ being the depth of water. In ordinary oscillating waves, the particles move in circles; in other cases where $\frac{\kappa}{\lambda}$ is small, the particles describe ellipses, which, in the case of the tide-wave, are extremely flat. In cases where the height of the wave bears a sensible proportion to the depth of water, the greatest velocity of the tide-stream downwards, exceeds the greatest velocity of the tide-stream upwards.

Mr. Russell, in his Report to the British Association, gives it as his opinion, that the tidal wave is of the first order, being, par excellence, "the great wave of translation." The following fact appears, however, to militate against this opinion. In positive waves of the first order, Mr. Russell shows, that the motion of the water is, throughout the transmission of the wave, in the same direction as the wave, and that there is a complete transference of a certain quantity of water to a position in advance. The fact alluded to is, that the direction of the stream, at a few miles from the coast, changes, when it is half-tide on the shore; the water flowing in the same direction as the wave, from half-flood to half-ebb, when it turns and runs in the opposite direction from half-ebb to half-flood. This fact appears to rank it as a wave of the second, instead of the first order, and to show that it is, in the open sea, purely a wave of the second order, or an oscillating wave. As a wave of the second order passes into water of a less depth than is requisite for its transmission in the pure form, it undergoes considerable change, and becomes increasingly more similar in appearance to a wave of the first order.

In many cases of its transmission up rivers and estuaries, it appears probable, that the tidal wave is changed into a wave of the first order, and when the coast projects considerably, at an angle to the direction in which the wave is moving; the waters, in such a case, are accumulated to a great height, and as they escape past the headland, to the water of a lower level, they propagate a wave of the first order; the case being almost analogous to the means used by Mr. Russell, in the genesis of his experimental waves of that order. Some of the effects, supposed to be produced by this operation, will be mentioned in treating of the action of the tide-wave in the British Channel.

The tidal wave in its various altered circumstances, seems to lend its aid in the wearing away of the coasts, and eventually, becomes the great carrier away of the débris.

On a general examination of the charts of the sea surrounding the British coasts, it seems probable, from the soundings and the materials found lying at the bottom, that the beds are not in the same condition as when Great Britain and the Continent were upheaved from below the waters, but that they are to a great extent, if not altogether, of subsequent formation; and on closer examination it will appear, that causes may be found for the variations in the depth and in the quality of the sand, or gravel, found in the different localities. Were the bottom of the sea irregular and full of hills and dales, like the adjoining land, the whole argument would fall to the ground; but, when an underwater delta, as it were, is found to be formed at the entrance to the British Channel, and the bottom of that and other channels, apparently of such a form as well-known causes in constant operation would bring about, there is strong reason for carrying the investigation further, and seeing, how far these causes are sufficient to produce the effects. The following extract from Mr. Stevenson's Paper on the Bed of the German Ocean is in point, as to the probability of the supposition.

"In thus disposing of the waste of the surrounding land, beyond the accumulation of the sunken banks in the German Ocean, we are not left at any loss for a distributing cause, as this is provided by the tides and currents of the sea; and with regard to their action, we have many proofs even at very considerable depths, by the breaking up of the wrecks of ships, the occasional drift of sea-weed and also drift timber, nuts, &c., into regions, far distant from those in which they are spontaneously produced. The dispersion of fishes, evinced by their disappearance from the fishing-grounds, in stormy weather, tends to show the disturbance of the ocean to the depth of 30, or 40 fathoms. This observation I have frequently had an

opportunity of making near the entrance of the Frith of Forth. Numerous proofs of the sea being disturbed to a considerable depth have also occurred since the erection of the Bell Rock Lighthouse, situate upon a sunken rock in the sea, twelve miles from Arbroath, in Forfarshire. Some drift stones of large dimensions measuring upwards of 30 cubic feet, or more than 2 tons weight, have, during storms, been thrown upon the rock from deep water. These large boulder-stones are so familiar to the Lighthouse keepers at this station, as to be, by them, termed 'travellers.' It is, therefore, extremely probable, that a large portion of the débris is carried down with the drainage-water of the higher countries, as before noticed, and ultimately washed out of the North Sea into the expanse of the ocean."

The case of the English Channel may be taken to illustrate the subject. The Irish Channel, or the North Sea would, probably, equally confirm the position. In following the tidal wave in its progress up the Channel it will be observed, that the time of high-water spring tides is very nearly the same at Ushant and in Bantry Bay; it may, therefore, be assumed, that a line at right angles to the line drawn between these places, would be the direction in which the tidal wave would proceed, provided there were no obstacles to its course. The Scilly Isles and the Land's End divide this wave unequally, the greater part proceeding up the St. George's and Bristol Channels, whilst the remainder passes up the English Channel. Of the former, the Bristol Channel receives a very large portion, which, in passing up the Severn, &c., causes the immense tides found there.

It is a wave of such considerable length, that when it enters between the points above mentioned, the depth of water remaining for it to proceed in, is, when compared to its length, very insignificant. It will, consequently, vary in velocity, as the square root of the depth of the water, (according to the results above quoted, as given by Professor Airy,) and the whole body of water will have the same velocity as that at the surface. The wave, in passing up the Channel, is constantly entering shallower water, its velocity will be, consequently, gradually undergoing reduction; but the velocity of the water set in motion for its propagation, will, on the contrary, be constantly accelerating, whilst, at the same time, the height of the wave, other things being equal, will be increasing. Now two, three and four miles an hour are not unfrequent velocities, in mid-channel; the least of which, Sir H. De la Bèche states to be sufficient for the translation of stones, the size of an egg.

In consequence of the ebb current, as shown by Professor Airy,

being stronger than the flood, in cases where the height of the waves bears a sensible proportion to the depth of water, and in mid-channel, (being increased in strength from the quantity of water thrown in from the projecting headlands, which water ebbs down the mid-channel, though it flowed up the sides, the bed of the Channel also falling in the direction of the ebb,) materials which were moved up by the flood, will be carried to a greater distance down by the ebb tide; so that, on the whole, the effect is a tendency to carry the gravel, &c., lying at the bottom, downward to the mouth of the Channel, there to form a submarine delta, which would probably extend some distance out into the Atlantic, but for Rennel's current, (Plate 17,) which passes athwart the Channel's mouth, defining to a certain extent the line of soundings.

The experiments mentioned in a later part of the Paper, seem applicable to the action of the tidal wave on the bottom, during its progress up the Channel. It is found, that oscillating waves, when they meet with an obstruction to their onward motion, have a tendency to pull down the materials that oppose themselves, and to dispose them in a definite form, having a foreshore and a beach; the depth at which the foreshore is formed, being dependent upon the character of the wave. It appears probable, that the 100 fathom line of soundings, is about the extremity of the foreshore formed by the action of the tidal wave. See the longitudinal section up the English Channel, in the line A B (Plate 18).

The above description applies principally to the action in mid-channel, or where the wave is enabled to proceed undisturbed, further than by the variation in level of the bottom. In observing the effects along the coasts, many interesting peculiarities are found. When the tidal wave is interrupted in its progress, by a coast at right angles to its direction, sand is heaped up, forming an inclined bottom, up which it runs with very increased velocity, (as far as motion of water goes,) and to an enormous height, whilst the water, so raised above the ordinary level, in running into the main channel, the water of which is much lower, forms the races which exist along the coasts. The Races of Alderney, and Portland, and the increased current round most headlands, are instances of this action. The effects of these races, forming waves of the first order, are to translate everything that impedes their progress, and to form deeps in their course; the material that they displace being deposited, where the velocity of the waves is diminished by their diffusion, or in the still water on each side, beyond their influence. The formation of the Hurd Deep and the deposition of sand on each side of it, are remarkable instances of this effect. The shingle which is driven

along the coasts, in the general direction of the prevailing winds, falls below the influence of the waves at these projecting headlands; not however to rest there, for the race then carries it onward, sometimes forming shoals at a short distance beyond the points, as is observed at the Shambles at Portland, the Skerries at the Start, the Swallow, &c., and at Dungeness, and other places.

After passing any headland, whilst the part of the wave in mid-channel passes onwards undisturbed in its course, the part near the side of the channel, wheels round into the adjoining bay; the size of the wave so derived from the main wave being very small near the headland, but increasing in size, according to the distance from it. In these bays the tidal current is slight, and the sand spreads very uniformly over the bottom, settling down there, in consequence of the comparative stillness of the water. There are, however, banks of coarse material, stretching from the several headlands in such bays; these are well known to the fishermen, as the resorts of certain descriptions of fish. They appear to be formed by waves of the first order, generated by the pent-up waters behind the headlands, carrying with them sand and shingle, which, escaping into the quieter water adjoining, form the banks described; part of the shingle is probably carried onward to the opposite shore, where it pursues its travels under the action of wind-waves.

The effect of the mid-channel wave, passing in the deep water with greater velocity than the wave in the bay, is, that reaching the opposite headland, before high water in the bay, an eddy current is formed, running alongshore back into the bay. When the coast beyond a headland falls back considerably, the tide in the hollow part of the bay is extremely small, the minor wave emanating from the mid-channel wave being almost lost. Instances of this are found at Weymouth, Poole, Christchurch, Wexford, and the coast adjoining.

The effects of the tide round the Isle of Wight, are very interesting. For instance, Poole Harbour enjoys an uncommon advantage, that of the ebbing and flowing of the tide, twice in twelve hours; it first flows regularly for six hours, and ebbs for an hour and a half, it then flows again for an hour and a half, and ebbs during the remaining three hours.* Lieutenant Mackenzie remarks,† that the flood runs slowly into Chichester, Langstone, and Portsmouth Harbours, until the western tide sets in; then it flows fast. In all these harbours the tide flows for seven hours, and ebbs for little more than five hours.

---

* *Vide* The British Channel Pilot, p. 58. 12th edition; by J. T. Hobbs, London, 1844.

† *Ibid.* p. 50.

Captain Ibbetson has kindly furnished the following information, as to the tides on the south coast of the Isle of Wight. He states, "that at St. Catherine's Point and the adjoining coast, it is high water at ten o'clock; that at half a mile from the shore, at Chale Bay, the flood runs for nine hours, the ebb for only three hours; and that all floating bodies gain to the eastward, the flood being the strongest."

The explanation that may be submitted of these peculiarities, is, that the first tide at Poole,—the first flow of the tide at Chichester, Langstone and Portsmouth,—and the former part of the long-continued flood at the south of the Isle of Wight, are the consequences of the tidal wave passing directly up the Channel, which would afford a very small tidal wave, emanating from it, to Portsmouth and other harbours, lying within the Isle of Wight; and that the second tide at Poole, and the flow at Portsmouth, &c., as well as the elongation of the flood at the south of the Isle of Wight, are the effects produced by the wave generated by the accumulated waters against the coast of the Département de la Manche, passing through the Races of Alderney, Sercque, &c., and onwards across the Channel to the English coast. The like explanation also holds good for the hanging of the tide at Havre and the adjoining coast at high water; at Havre it continues for an hour and a half.

An examination of the Channel chart shows, that the French coast, in the Département de la Manche, extends nearly half way across the Channel, and thus interrupts in its passage the flow of that proportion of the tidal wave. The immense height to which the tide rises there, in consequence, is well known, being upwards of 45 feet at the highest part, and generally among the islands, from 30 feet to 40 feet at springs. Considerable effects from such a large quantity of accumulated water may fairly be expected to be perceptible even at great distances.

On referring to the time of high water on the coast, it will be observed, that—

	h.	m.
At Start Point, at springs, it occurs at . . .	5	58
At Portland	7	15
At Beachy Head, upwards of 50 miles from the Isle of Wight	10	16
At South Foreland, upwards of 100 miles from the Isle of Wight	11	5

The time of high water, under ordinary circumstances, at the Isle of Wight, would be half-past eight, instead of which it is—

	h.	m.
At St. Catherine's at	10	0
Whilst it is not high water at Portsmouth till .	11	30
Whilst it is not high water at Southampton till .	11	55

It is high water at Cherbourg about eight o'clock, from which port to St. Catherine's Head, the wave would travel in less than two hours, bringing the high water at that point, at nearly the observed time. This second tidal wave would set much more directly into Portsmouth, &c., and cause the rapid flow as described by Mr. Mackenzie. The tide at Poole having already ebbed for some time, the wave on reaching that part, would produce all the peculiarities of a second tide.

Very high tides are generally found on the French coast; this arises from its concave form, causing the tidal wave to be always striking against it, and thus accumulating the water. The English coast, on the contrary, is more nearly a straight line, along which the wave passes comparatively without interruption. The height of tide decreases at Boulogne, where the water is able to escape through the Straits of Dover, in the same manner as the height of the tide at Alderney is considerably less than at Mont St. Michel, &c.

The tides at Folkstone, Dover, &c., rise higher than at any places on the south coast of England, owing to the shape of the French coast, and the narrowness of the Straits of Dover; the water not being able to pass on, so fast as it is forced forward, is accumulated, and forms the high tides found there.

On examining the times of high water in the North Sea, it will be observed, that it becomes gradually later, towards the east and north, till the Thames and the mouth of the Rhine are passed, whence northward, it is at an earlier hour, showing that the meeting of the tides, is, correctly speaking, at these places, and not as marked on the charts, at Dungeness and Cape Grisnez. The accumulation of water to the west of Dover at every high tide, in rushing through the Straits, causes the disturbed state of the sea there, and it might, with propriety, be called the Race of Dover. The consequence of the current of water from the English Channel into the North Sea, being during the hours of high water, continuing for a long period, and rushing with at least equal velocity to that in the opposite direction, is, that a much larger quantity of suspended matter is carried into the North Sea than is returned from it into the Channel. The fact of its rushing into the North Sea, and meeting there with the northern tide, must make the water comparatively quiescent, which will be increased by the great extent of that sea; the sand,

&c., in suspension has, consequently, a favourable opportunity of settling down there, and forming extensive shoals.

On the other hand, the return-current joins the ebb-current of the Channel tide, and having no quiet resting time, passes beyond the Straits of Dover down mid-channel, whilst part of the sand and silt in suspension subsides at half-flood: the remainder being brought back again by the flood tide to the Straits, is carried into the North Sea, being at the same time, replenished by the action of the flood tide along the coast, especially in stormy weather.

That which was left in mid-channel below the Straits, would not remain there, but being disturbed each tide, would, by degrees, move down, till it rested at, or near, the entrance of the Channel.

The fact, as stated in evidence before the Harbour of Refuge Commissioners, of the anchorage in Dover Bay being chalk, with a slight coating of sand, is corroborative of this view of the subject. The quantity carried backwards and forwards varies considerably with the winds, &c.*

The interesting question,—whether England was ever connected with the Continent, at the Straits of Dover,—here presents itself. A Prize Essay was written by the celebrated Desmarest, to prove that this had been the case. He founded his principal arguments on the identity of composition of the cliffs on the opposite sides of the Channel; on a submarine chain extending from Boulogne to Folkstone only 14 feet under low water; and on the identity of the noxious animals in England and France, which could not have swum across the Straits, and would never have been introduced by man. The raised beaches on the coast of Brighton, &c., appear to favour the supposition; for had the land extended across, the tides would have risen to an immense height, forming these beaches, which, when a passage was formed through the Straits of Dover, and the water consequently, being freed, rose to a less height, would be left on the cliffs. It would seem probable, that the bottom of the Straits of Dover must, even now, be lowering, from the constant stream of water passing backwards and forwards; the effect of this would be to lower the level of high water on the adjoining coast in the Channel, and to raise that along the coast of Holland, &c. The raised beaches on the coasts of Devon and Cornwall may, probably, be explained in the same manner, as the contour of the coasts has, no doubt, been very materially altered, in the course of centuries;

---

* *Vide* Captain Washington's Reports to the Admiralty, and pages 73 to 77 of Report on the Harbour of Refuge, to be constructed in Dover Bay. London, 1847.

and headlands formerly projecting at certain points, but now washed away, would produce all the phenomena, necessary for the effect now perceived. The various levels of these raised beaches are much more satisfactorily explained on this supposition, than according to the usually adopted opinion of the land having been raised, and with it the beaches, which, under such circumstances, would probably have presented a great uniformity in their level. The great variety in the height to which the tide rises, on various parts of the coast of England and France, from 2 feet to 70 feet, is sufficient excuse for very wild flights of the imagination.

The tidal water, in ebbing down the Channel, does not meet with so many obstacles to its course, as it did in flowing; it partakes more of the character of a current than of a wave, in consequence of the quantity of water thrown into it from the projecting headlands on both sides of the Channel; besides which, considering it purely as a wave, it has, as shown by Professor Airy, a greater velocity in ebbing than in flowing. This is a most important feature in the progress of the tidal waters, as regards their power of conveying away the débris of the coast.

The general action of the tidal wave in the Channel seems to be this:—As it passes up it travels fastest in deep water, whilst the velocity of the water in its transmission is least; its velocity is impeded in passing over the shallower water, whilst the velocity of the water, in its transmission, increases in a like proportion. On the ebb, the tidal waters having been forced toward the middle of the channel, return more as a current than as a wave, with the greatest velocity in mid-channel, or deep water, and the least velocity in the shallow water. The effect of this action is, that the débris from the cliffs of the coasts, is driven up by the flood tides, (assisted by the prevailing winds,) and after being carried into the mid-channel by races, &c., is borne down to the mouth of the Channel by the return of the tidal waters; so that, as a general feature of this combined action, there is a constant encroachment on the coasts going forward. There are special cases which appear exceptions to this general rule, but they allow of explanation. An example is afforded in the large tract of flat country around Bridgewater, reclaimed from the sea; it is only necessary to suppose the land joined between the Steepholm and Brean Down at the mouth of the Axe, and all the district would be again covered by the tides.

It might be interesting to investigate, how far the whole, or any of the Romney Marshes are a consequence of the breaking through of the sea at the Straits of Dover. The present increase, however,

is explained by the waves driving the shingle to Dungeness, in greater quantities than the race adjoining is able to carry it forward.

The extensive flat country in Holland may have been formed before the breaking through of the Straits of Dover, when the tides probably rose higher than after that event. Subsequently, as the Channel tide escaping through the Straits, forced itself further northward, the tides would again increase in height along that coast, submerging lands, which had been by the previous operation reclaimed from the sea.

The general action of the flow of the tidal waters up and down Channel has already been considered; there are besides these, the very important forces, of wind-waves acting on the coast, also in operation. These are the principal agents in the encroachment on the land; their action would, however, cease comparatively soon, but for the action of the tidal currents above described. There are three effects observable from the action of wind-waves on the beach, which have been well described by the late Mr. Palmer in his Paper on the Motions of Shingle Beaches *:—

1st. As the Accumulative action by which the shingle is heaped up on the beach;

2nd. As the Destructive action by which it is drawn down and flattened;

3rd. As the Progressive action by which it is carried along the beach.

Mr. Palmer says, he observed at Dover, Sandgate and Folkestone, "that when ten breakers arrived in a minute, the destructive action was but just commenced, and when only eight breakers arrived in the same period, the pebbles began to accumulate."

The consideration of the change that takes place in oscillating waves, as they approach the shore, suggests an explanation of the first two actions. Whilst the water is of sufficient depth for the transmission of the wave in its pure form, its effect on the bottom is insensible; but as the depth of water becomes less, the case mentioned by Professor Airy,—"that the velocity of the ebb is greater than that of the flood, when the height of the wave bears a sensible proportion to the depth of the water,"—comes more and more into operation; and the effect of this upon a beach must be the destructive action mentioned by Mr. Palmer. This destructive action goes on increasing, until the wave breaks, after which, as shown by Mr. Russell, a wave of the first order is generated,—a wave of Translation,—an Accumulative wave.

* *Vide* Phil. Trans., 1834. Part i. p. 567.

Experiments show, that waves of the same size, acting for a length of time, on gravel, or sand, give it a certain definite form.

To investigate this form, a trough, 20 feet 9 inches long, 16½ inches wide, and 9 inches deep, was used. The waves were propagated by a board working on hinges, at the bottom of the trough; the board being moved by a crank attached to wheelwork, moved by a weight, and regulated by vanes. The results show, that the tendency of each oscillating wave, when it changes its character, and breaks on a beach, is to cause it to assume a certain definite form. The further removed the original outline is, from that form, the greater will be the action in a given time.

If, when waves of a certain size act upon it, the beach is flatter than that which these waves would form, the beach will be thrown up at the upper part, above the former beach, and be pulled out below.

If, again, the beach is at the same angle, or steeper, there will be no heaping up; but a process of pulling down, increasing as the beach is steeper.

In the case of a beach, subjected to waves of lessening size, at fixed intervals, but the level of the water remaining constant, the shore would form a succession of terraces.

It is easy to form such a succession of terraces. The degree of encroachment would greatly depend upon the depth of the water adjoining, affording facility for withdrawing the material. The tendency will always be to encroach.

When the level of the water varies, as caused by the tides, the case becomes much more complicated, as the height of the water, and the size of the waves, are both variable; moreover, the spring and the neap tides materially alter the case. The violence of the winds also affects the average line between high and low-water mark.

The curve of the flow of the tides shows, that the water continues at nearly the same level for a considerable time, at high and low water; and that at half-flood and half-ebb, the water changes its level much more rapidly.

The result of this is, that the waves have a longer time to act upon the beach, at high and at low water, and comparatively a short time at half-tide.

Supposing the high and low-water marks and the size of the waves to continue constant, what would be the form assumed by the beach? The state of rest would, evidently, not be arrived at, until the waves, at low water, cease to draw down the beach, (this condition would be met by a long flat foreshore, the end being below the influence of the waves,)—and at high water, until they had

ceased to heap it up, (which would be met by a beach being steep, at the top;) for as the water rose, the waves would cease to act on the end of the foreshore and could not, therefore, heap up anything that had been pulled down, nor could they pull down anything that had been heaped up at high water, when the tide began to ebb. From the time that the tide began to rise till it attained its highest level and sunk again to low water, the waves would have a tendency to form new foreshores, corresponding with the varying water-level. The quantity so pulled down will be greatest at high water, when the waves continue to act for the longest time. Now before there can be any equilibrium, or state of rest in the materials, this part so pulled down must be thrown up again by the waves; and as the waves will have a much shorter time to throw it up than they had to pull it down, the shape of the beach must be such as to afford it an advantage in acting upon it. It will, consequently, be flatter near the top.

The form that would be assumed, when a state of rest was attained, would, probably, be:—a long foreshore, the end being below the influence of the waves;—the foot of the beach rather steep, so as to give the waves, as the tide rose, an advantage in pulling down, in a short time, the material that had been thrown up at low water;—flat again below high-water level, so as to give the waves, as the tide receded, an advantage in heaping up, in a short time, the material drawn down during the longer action at high water;—the beach above high water assuming the same steep form as it would, in the case of the level of the water and the size of the waves being constant. It is hardly necessary to observe, that this form would vary immensely, according to the depth of the action of the waves compared with the rise of the tide. In the case of ground-swells the waves have been known to break at high water, at a great distance from the beach, and to roll in upon it as waves of translation. They, of course, came in as waves of translation, heaping up the beach during the whole of the tide, and the depth of water in which they broke, was greater than the rise of the tide.

When the levels of high and low water continue the same, and the size of the waves varies, if the waves are smaller than those which formed the beach, a new foreshore at a higher level would be formed, and an encroachment on the beach would be the consequence; if the waves are larger, a process of lowering the foreshore would commence, by pulling it down at its outer end, and heaping part of it on to the beach; the tendency being to lower the foreshore and increase the beach, the reverse of the former case.

When the tides vary,—supposing waves of the same size to be

acting,—during the neaps, the tendency would be greater to raise the foreshore and to encroach upon the beach; in the case of spring tides, the contrary.

During violent on-shore gales the water is altogether raised, so that the medium line between high and low water is sometimes raised several feet. The greatest encroachment will, on such occasions, take place during neap tides, for it gives the greatest depth of water over the foreshore at low water.

The nature of the material composing the beach will always affect the form that it will assume, since the finer the material, the less inclined is the surface it will form.

The extract given above from Mr. Palmer's Paper appears, in some measure, to corroborate this view of the operation; if, as appears probable, the number of waves breaking in a given time, is an indication of their size, fewer large waves breaking on the shore in a minute, than small ones.

The progressive action varies considerably, being dependent upon the angle at which the waves break on the shore. The more acute the angle, the greater is the progressive action. This angle is very much modified by the form of the foreshore, which generally tends to make it less acute. It may be observed during a storm, that the waves in the deep water proceed forward, in the direction of the wind, till they arrive in the shallower water, when the velocity of the part which first reaches the shallow, being lessened, the whole wave wheels round, and breaks nearly at right angles on the beach; this very much lessens the effect in some places, and enables the beach to rest against the cliffs, instead of being heaped up against a headland at one end, leaving the other end bare. When there is no shallow foreshore, the wave breaks nearly in the direction of the wind, and its power of transporting is, consequently, greater, and the onward motion of the shingle is increased. The extent of this motion varies with the force and direction of the wind, and the distance over which it has acted on the waves.

The wind blowing from the Atlantic sends a greater sea into the Channel, than any wind blowing across, or down Channel can raise, and the winds between north-west and south-west, therefore, produce the greatest transporting effect. The south-west winds are the prevailing winds, blowing nine months in the year, and frequently with great violence. There is frequently a heavy swell, known as the 'ground-swell,' which sets in from the mouth of the Channel and breaks with great violence upon the shores; this swell is supposed to result from storms in the Atlantic, the waves raised by which are transmitted till they break on some opposing shore.

It will be seen from these general remarks, that the motion of shingle on any beach, is dependent upon the extent to which it is exposed to the waves, the angle at which the waves break upon it, and the violence of these waves.

Now, although the prevailing winds in the Channel are also the most violent, and consequently, on the whole, drive the shingle along the coast to the eastward, the winds from the opposite quarters exert a very material influence on the beaches; for in very many instances, the shingle which has been thrown up nearly at right angles to the former, (when, of course, the waves can have very little power of moving it forwards), will, in a short time, be carried back by the latter acting upon it at a very considerable angle.

This is very important and suggests the best direction for the construction of groynes for the collection of shingle: the object of which is to give the prevailing waves the least favourable means of forcing the shingle forward, and to assist as much as possible, the less violent and constant winds, in driving it back again. A groyne run out in a slanting direction from the prevailing winds, appears the most favourable. The power of the prevailing waves to sweep out the shingle from behind the groyne and to carry it forward, would be greatly diminished, and they could only act on the beach some little distance beyond the groyne. On the other hand it would encourage the accumulation behind it, of shingle driven by the waves from other quarters, whilst as these impinged on the groyne on the outer side, they would gather strength as they ran along it, and would exercise considerable power in carrying the shingle back. The Chesil Beach and Dungeness present instances of the power of the prevailing wind-waves to drive shingle along the shore, till it arrives at right angles to their direction, when it is only subject to the accumulative and destructive action, and the beach, consequently, grows outwards into the sea. The great height of the Chesil Beach is accounted for by the tide rising higher, and from the violent south-west seas driving directly upon it, their accumulative action being expended in heaping up the shingle, instead of driving it along the coast; the effect increasing to the eastward, where the shingle lies most at right angles to the direction of these waves. The same more direct accumulating action seems to account, also, for the larger pebbles being found to the eastward.

Mention should not be omitted of the very great effect, in certain situations of the currents, derived from the tidal wave, in aiding encroachments upon the coast. This was very remarkably exemplified in the landslips that occurred in the neighbourhood of Lyme Regis, in 1839. It appears from the "Channel Pilot," that there

was formerly a roadstead for shipping immediately adjoining, and that after the slip occurred, the bed of the sea was raised 40 feet above the surface, and there were reefs and islands where none before existed. The formation of this roadstead must be attributed to the tidal current which, sweeping with considerable velocity along this part of the coast, and acting upon the soluble and easily-removeable materials of which the substrata are composed, would deepen the water as represented.

The fact of the water being thus deep, immediately adjoining the cliffs, must have aided very materially, though it was only one of the several causes which were in operation at the time, to produce the landslip.

There is one most important feature in a coast so situated, namely, the impossibility of guarding against encroachment. In cases of inroads being apprehended from the waves of the sea, it is not only possible, but certainly in very many cases, quite practicable, to provide against their effect by groyning; but when, as in the case of the coast of Dorsetshire, there is, in constant operation, a current running along the coast, with very great velocity, close in-shore, and able every time it acts, to carry something away with it, it becomes barely possible to guard against its effects, for wherever the foundations are laid, they are liable to be undermined and overthrown, and would, without question, eventually be so.

The action of the tides and wind-waves in the Channel has been, as yet, considered, as though it were simply bounded by irregular coast lines, but in reality, these lines are not continuous, there are innumerable streams, rivulets, rivers, and estuaries running inland all along the coast, which act a very important part in the operations. It is, therefore, necessary to investigate the influence they exert, and how far they are themselves affected.

The Author has endeavoured to show, that the effect of the waves is to carry shingle, &c., towards the east, until arrested by some projecting headlands against which it is heaped, part being eventually carried round it and forwards, by the currents and waves; but the mouths of estuaries also form barriers to its onward motion. What then becomes of the shingle when it arrives at the mouth of an estuary? It cannot leap across, and being forced forward by the prevailing wind, it cannot heap itself up; it must, consequently, fall into the channel of the estuary, there to be moved backwards and forwards until it reaches a situation, where the velocity of the water is not sufficiently great to disturb it. This is a most advantageous case for rapid encroachment upon the adjoining coast; much more so than when the shingle escapes round headlands, for there it must

previously have been heaped up, to a great extent, against the projection, before it could get round the point; preventing, whilst it so lay, the encroachment of the sea on that particular part. In the case now under consideration, however, there is a ready means of discharge for the shingle into the mouth of the estuary; and with such an estuary for the deposit of the débris, the encroachment on the coast would be very rapid, were the materials composing the cliffs, easily undermined by the waves. Where the material is rock, the process would be much slower, but still the effect of expediting the encroachment would be sensibly felt, for the shingle being removed from the foot of the cliffs as fast as it was formed by their fall, deep water would be maintained near the shore, enabling the waves to approach unimpeded, to within a short distance of it; when breaking over the shallow ground adjoining, they would drive with their full force against the cliffs instead of on the beach, as in other cases.

The Great Western Bay,* which is of very considerable extent, reaching from Start Point to Portland, a distance of about fifty miles across, with a depth inland of about twenty miles, demands attention as exemplifying the action of the forces already treated of. There appears strong evidence to prove, that this bay is, to a very considerable extent, if not altogether, the result of continued encroachments of the sea upon the land. This speculation may be considered as rather trenching on the province of geology than affecting the profession of the Engineer; but inasmuch as Engineers are constantly called upon to speculate, as to what is likely to take place in certain cases, they will be better enabled to do so, by maturely considering what have been the operations of nature, under similar, or analogous circumstances. In the Dart, the Teign, the Exe, the Axe, the Otter, and other rivers running into the West Bay, the tide has formerly risen to a much greater height than at present. There is no want of proof of this fact. It will suffice to mention, that the tide is recorded to have flowed at least twenty miles above Exeter, whereas it does not now flow up to that city; and in the Axe, a large vessel, which could not possibly have got in at the present entrance to that river, was found embedded in alluvial deposit. These rivers, when continued to the outer margin of what is now the bay, as they would have been in the case supposed, must, at their mouths, have terminated in very considerable estuaries.

* A Chart of this Bay will be found in Minutes of Proceedings Inst. C.E., 1852-3, vol. xii., plate 2.

Such estuaries would be more open to the direct flow of the tidal wave, and would, consequently, have much higher tides, than lying as they now do, deeply embayed. A rise of tide above Exeter and Newton of 50 feet, or 60 feet, is no preposterous supposition under such circumstances.

The geology of the neighbourhood confirms the position, as the following extracts will show:*—

"We observe beds up the valleys of the Otter and Exe, which could scarcely have been deposited by the sea at its present level, and which yet contain shells such as are commonly found in the estuaries at the lower part of the same valleys. . . . There are beds also in the lower parts of the valley of the Axe which would appear rather the raised bottom of an estuary, than a mere accumulation of alluvial matter by the river at the present level of the sea. . . . It is not improbable, that though the flat lands at the heads of most of the estuaries of the southern coast of Devon and Cornwall may, in a great measure, be due to the check the rivers flowing into them receive from the tide at its present level, much of the detritus accumulated in the valleys may have been so, when the tide rose to a higher level."

At various parts of the Exe and to within a few miles of Exeter, there exist behind the alluvial deposit, bold cliffs, which were not likely to be the result of any tidal waters, such as are now in operation in that estuary, but seem to indicate a former violent action of a large body of water. This is also the case on the Teign, where there are bold cliffs of very hard material now standing, to attest the violence of the waters that formerly raged against them.

In the vicinity of Newton, about six miles from the present entrance of the Teign, there are most interesting geological facts. The tidal waters must, at one period, have spread over a very extensive surface, forming a magnificent tidal lake, surrounded by diversified and beautiful scenery. Into this large expanse of water the streams rushing in all directions, with great violence from the adjoining hills, would find a resting place for the detritus they brought down in solution and mechanical suspension. The neighbouring granite chain of Dartmoor and Haldon, its summit capped with green-sand, would in the early stages, afford an immense supply of material for the land-waters to convey, whilst the quantity of rain, falling at the period when the land was upraised, would, from the greater extent of evaporation, and from the probably

* *Vide* Sir H. De la Bèche's Report on the Geology of Devon, Cornwall, and West Somerset, page 425. London, 1839.

disturbed state of the elements, be much greater than is experienced at present; the finer particles being carried onward and slowly deposited at the bottom, whilst the rougher stones and gravel were dropped nearer the head of the estuary.

The following section of one of the potters' clay-pits in this neighbourhood, shows the greater part of the good potters' clay to be deposited beneath the level of the present neap tides, at low water, whilst the surface of the ground is 39 feet above the level of ordinary springs.

39 feet above springs. Surface of ground.

15 feet.	Coarse Gravel.
30 feet.	Greyish Black Clay. Not used.
13 feet.	Good White Clay. 5 feet below present spring tides low-water mark.

Clayey Sand—very fine.

The object of drawing attention to these deposits is to show, that the tides did, at one period, rise in these valleys to a very great height. The gravel-beds found upon the caps of the cuttings, bordering the river, which have been made for the South Devon Railway, also attest the former much higher level of the tides. Now this increased height of the tides can be accounted for, by supposing the mouths of these estuaries to have extended originally to the margin of the bay. Assuming them to have been formerly so situated, it will form an interesting subject for investigation, how the changes have been brought about, from the initial formation of West Bay with its magnificent estuaries, to its present state, with a deep indentation of twenty miles, the mouths of some of its rivers literally closed up by shingle; others again barely able to maintain a passage to the sea; whilst two of the largest rivers in the South of Devon, the Exe and the Teign, which discharge their waters into it, are barred across, and can with difficulty maintain a navigable channel.

On examining the Channel chart it will be observed, that the land terminating in the Start Point, is the first important obstruction on the south coast of England, that the tide meets with in its passage up the Channel, and that the velocity of the current is now three miles an hour round this point; its direction being in the line of the supposed former estuaries of the Exe, the Teign, the Otter and the Sid.

The Start is composed of very hard material, upon which the sea has probably made very slight encroachment, since England was first uplifted from below its bed. The cliffs are of a hard description along the coast to Berry Head and passing Torbay, the cliffs round which are, to some extent, of the softer sandstone formation. The hard mountain limestone appears again at Hope's Nose, beyond which, throughout the bay till near Portland, at the further extremity, there is a material easily yielding to the violence of the sea.

On examining the Ordnance maps, showing the mouth of the Dart, the submarine continuation of the valley is very striking, arguing the very small quantity of detritus which has been swept along the coast to it, and showing the probable slight encroachment on the land, between it and the Start Point. On observing the line of soundings further to the eastward, there are striking irregularities which may also be supposed to indicate the former coast line and process of encroachment. There has been considerable discussion as to the site of Moridunum, the principal station of the Romans in this part of the island: the distances given are thirty-six miles from Dorchester and fifteen miles from Exeter.

No line of coast can be conceived much more favourably situated for the sea to make inroads upon; the tidal wave traversing the outer margin of the coast generally; a strong wave of translation setting fairly up the estuaries of the Exe, the Teign, &c., occasioned by the pent-up waters, between Plymouth Sound, and the Start Point, racing round that point at the rate of three miles an hour; the coast being exposed to the action of the prevailing, and also, most violent south-west winds, with extensive and deep estuaries, into which the currents and waves may carry the débris; the material forming the cliffs being, at the same time, ill-suited to withstand the action of the tides and waves; the extensive space up the estuaries, ready to receive the tidal water, which by its reflux should level down the débris thrown into their mouths; all these, form, together, a combination of the most important destructive elements.

The rate of the encroachment would vary very much, according to the height and the different nature of the material composing the cliffs; and upon the rate at which the cliffs gave way, in particular localities, would depend, in a great measure, the effect of the waves and currents upon the remaining coast.

As the water, during the transmission of a wave of translation, has the same velocity at the bottom as at the surface, the limit of the depth to which it is able to excavate, depends upon the depth of the channel into which it carries the material it wears away. When the channel is filled up, its abrading power will cease, unless beyond

it there is again deep water for the deposit. When the coast on the east side of the Exe was so far removed back, that the wave of translation from the Start, instead of running up the estuary of the Exe, swept along the coast, the Axe would begin to receive a more complete effect from the direct tidal wave. When the débris from the coast had filled up the channel of the Axe to the level of the adjoining bottom of the sea last encroached upon, the removal of the land in the eastward part of the bay would be a process much slower than that which has been considered; for up to that period the débris had been easily got rid of in the entrances of the Teign, the Exe, the Otter, and the Axe, to the eastward of which, it seems probable, that the rivers ran parallel to the present coast, and had their entrance between Portland and the main land. The débris must then have been driven along the coast by the in-shore current, and the wind-waves, to Portland and thence, by the Race, into mid-channel.

The effective operation of the tidal in-shore current in this process, as was before mentioned, has been lately remarkably manifested, by the depth of water adjoining the great landslip, near Lyme Regis, previous to the slip taking place.

The space now occupied by the Chesil Beach, was, probably, formerly the channel of an estuary, Portland having been connected to the main land. That the Chesil Beach should lie parallel to this supposed channel appears singular, but it is not more so, than that it should run nearly parallel to the adjoining main ranges of hills. The Chesil Beach lies nearly at right angles to the prevailing winds, which, driving the shingle to this part, although unable to carry it forward, accumulates it. Along the Chesil Beach the shingle will continue to accumulate, until the waves of the sea bring a less quantity to it, than the in-shore current can convey past the Bill of Portland into mid-channel. There is a constant approximation to this condition, as the coast to the westward becomes more encroached upon and formed at right angles to the prevailing winds.

The following extract * shows, that the process of encroachment in this bay is, even now, going on rapidly.

"The rocks between Teignmouth and Lyme Regis suffer much loss from the action of the breakers upon them, to an extent, that if the latter possessed the average force of those which wear away the coast last mentioned, (the north-west coast of Cornwall,) very con-

* *Vide* Sir H. De la Bèche's Report on the Geology of Devon, Cornwall, and West Somerset, page 440. London, 1839.

siderable inroads would be made upon them, and the bay would be much enlarged northward, in the course of a few thousand years. No doubt, much loss of land, in the vicinity of Lyme Regis, especially, is occasioned by the slipping of chalk and green-sand, (as we have had elsewhere occasion to represent,) over the lias and red marl into the sea, producing picturesque undercliffs, the fragments of the fallen rocks protecting the coast from the loss of land it would otherwise sustain; but the movement thus caused, if the breakers did not carry away the fallen rocks, would be comparatively trifling, equal only to the landslips observed in the valleys near Lyme Regis and Axminster, where, from a similar cause, the green-sand on the slopes of some parts of the hills, slides upon the mud and clay to lower levels. Independently, however, of the loss by landslips, the lias cliffs near Lyme Regis are readily seen to be washed away by the breakers, as may easily be observed between Charmouth and that town, as also to the eastward of it.

"Considerable waste of this coast has thus been occasioned within the memory of persons now living; a waste first recorded, we believe, by De Luc, and one which is still proceeding at a considerable rate, the fall of the cliffs being frequent, particularly in bad weather.

"Much loss of coast is sustained near Sidmouth, particularly in the direction of High Peak, the small green-sand cap on the top of which, will disappear at no distant date, geologically speaking, and be only known to have existed, from the geological maps now constructed of that part of the country. The isolated red sandstone and conglomerate rocks on several parts of the coast, the evidences of its former boundaries between Sidmouth and Teignmouth, are often worn away by the breakers, in a manner well illustrating the unequal resistance offered by different portions of them. One of these isolated masses, named the Chit Rock, which long rose above a ledge on the west of Sidmouth, was, a few years since, upset, in consequence of a central part of it having been finally worn so thin, that the upper portion was knocked off by the breakers in a gale of wind."

But perhaps the most interesting part of the question remaining to be considered, is the process by which the noble estuary is passing into the lamentable state of the Exe and the Teign, with power barely sufficient to sustain their channels navigable? There is now hardly any tidal current sweeping along the shores at this part of the coast; the contest comparatively remains only between the billows and the estuaries, endeavouring by the flux and reflux of their waters, to maintain open channels into the sea. The extent to

which they are enabled to accomplish this, depends almost entirely upon the remnants of the estuaries, which, during each tide, receive a large body of tidal water. This is not, however, the case with many smaller streams around the West Bay, the mouths of some of which, as the Char and the Bredy, are frequently choked up; whilst those of others are constantly so, as the Sid, the Branscombe River, &c., forming in some cases, fresh-water lakes, the waters of which gradually percolate through the shingle.

On examining the present state of the Exe and the Teign, a very striking difference in the appearance of these rivers will be observed, for whilst the entrance of the former is driven to the extreme east, that of the latter has been forced as far as possible to the westward; there being, in each case, very deep water inside of the tongues of shingle. This may be explained in each case. Attention should be first directed to the absence of any causes, now in operation, which would form the inner tongues, whilst the outer ones are at present subjected to the action of the waves, and their formation can be explained, by the drift of shingle from the adjoining coast. A former action must be looked to for an explanation of the formation of the inner tongues.

When the land was so far encroached upon, that the common entrance of the Teign and the Exe was destroyed and these estuaries became independent, what would be the action? The headland beyond the Exe would be constantly receding, but for a long time, intercepting the tidal wave of translation from the Start. At first the water would be turned from it nearly in a straight line up the Exe; but as the headland was forced back, and the coast became inclined to the Exe, the eddy flood would strike across, instead of directly up the estuary, carrying with it the débris from the cliffs, and depositing it athwart the channel, as the inner tongue is found to be placed. As the coast receded, this eddy would become less and less, until as now, it became barely perceptible. The high tides would continue both in the Exe and Teign during this period, with, consequently, a considerable tidal current sweeping along the cliffs between the Start and the mouth of the Teign; which, carrying the débris along with it, would cause a deposit similar to the inner tongue of the Teign, on the opposite side to that of the Exe. As the headland beyond the Exe receded, the current along the coast from the Start to the Teign would diminish, and the height of the tides gradually become less, until, entirely freed, the wave of translation would pass, to achieve new victories in the Axe &c. to the eastward.

What, during this process, has become of the land which separated

the estuaries? The remains of it, headed by the Parson and Clerk rocks, are still standing to read a lecture to mankind of the instability of all earthly possessions. Of a decidedly harder and higher material, it had comparatively withstood the action of the encroaching forces, until the period when the tidal wave, &c. was enabled to free itself to the eastward, leaving the coast behind with much smaller tides,—barely any tidal current,—and the future battle to be fought between the waves of the sea, and the flux and reflux of the estuary waters. The two estuaries were then flowing out, the one near Langstone Point, which is well known to have been the case, and the other across the present Teignmouth Dan, which is, to some extent, corroborated by the remains of piles seen occasionally at low water. The buildings formerly erected on these piles, were remembered by the parents of persons now living, to have been salting-houses, (there having formerly been carried on here, an immense Newfoundland trade, which is still continued, though much diminished in importance;) these can hardly be supposed to have been built into the sea, but most probably, within the mouth of the estuary. The neck of land jutting out between the Exe and the Teign, would now afford the material for the future contest with the estuaries. No shingle could be brought round the point in either direction, by the waves,—the currents have almost disappeared,—the material must, consequently, be driven, right and left, from the most projecting point towards the mouths of the estuaries, there to accumulate and force their mouths from it. So long as these entrances continued deep, the process of encroachment on the land would go on rapidly; but as the shingle stopped up the entrance, and began to accumulate there, the beach would form against the cliffs; the cliffs also becoming more at right angles to the wave, would be able better to resist the encroachment, until there would be a comparative, although not perfect, equilibrium.

There is a most interesting process now going on at the mouth of the Exe, to which public attention has been very forcibly drawn by Mr. Peacock, of Starcross, who, being a native of that place and a Captain in the mercantile marine, has had, almost from childhood, his attention drawn to the subject. From his Paper on this subject, some of the following facts have been obtained.

Whilst the supply of shingle from the before-mentioned neck between the estuaries, was greater than the river Exe could take away, during its flux, and reflux, the tongue formed by it, known as the Warren Sands, continued to extend itself.

Polwhele, in his History of Devon, 1797, says:—" Within the

memory of man, the Warren consisted of more than three hundred acres, it is now scarcely two hundred; full fifty acres have been washed away within the last twenty years." But when the state of equilibrium was passed, and the estuary could carry out into the deep water more matter than was brought to it, the Warren began to diminish, so that, as stated above, it had been diminishing for a long period, and now Mr. Peacock states it to contain only forty acres, or fifty acres, which are not covered at high water.

The mouth of the estuary has widened very materially, so that now, the waves at high water have free ingress to act upon the inner tongue. On this tongue, within the memory of many old persons now living, there were formerly a farm-house and strawberry-gardens, and it stood considerably above the present high-water mark; even as late as 1824, part of it was 6 feet above high water. It has, however, been the custom to allow vessels returning from the port, to take ballast away from it, which has had the effect of expediting its destruction. The sea now rages over it in stormy weather, and spring tides, causing a rough sea at Starcross, to which it used formerly to act as a breakwater, and in so washing over it, the sea is now hastening, as very properly pointed out by Mr. Peacock, the complete destruction of the estuary, by filling up the course of the stream, and converting the whole into one huge sand-bank, interspersed with innumerable small channels, none of them navigable.

The obvious remedies for these evils are—groyning, to prevent the conveyance of the Warren shingle into the mouth of the estuary; and as proposed by Mr. Peacock, the construction of a breakwater on the inner tongue, so as to prevent the action of the sea within the estuary. The whole case calls loudly for the attention of the Government, and of persons interested in the prosperity of the port: as there can be no doubt, that the Exe might, at no very considerable expense, be made not only a good, but a stable port, likely to continue, with little variation, for centuries to come.

The Teign will also be subjected to the same action in the course of time, if it has not already commenced; in both cases the supply of shingle will be materially affected by the South Devon Railway works, for the protection of which every means will be taken to stop the progress of it to either river. The present direction of the most important entrances to the Teign, and the constantly changing nature of them all, exhibits a state very far from that of equilibrium. There is little doubt, that an entrance might be made secure and constant, at comparatively little cost. The points required are, that the cliffs to the westward be prevented from being

encroached upon by groyning, and that the sands of the Dan be prevented from being washed to the mouth of the harbour, thence to be carried up the river, forming the shoals found there, or out to the sea on the reflux of the tide. Piers run out into deep water on each side of the present entrance, would secure comparatively pure water for the estuary, and would impede the rate of silting up, which by altering the quantity of water admitted each tide, is one of the most formidable agents in the process of destruction of the harbour.

In conclusion, the Author will endeavour to review, in as concise a manner as possible, the various actions to which the material of the coast is subjected. It is generally pulled down from the cliffs within the action of the waves, either by being undermined by the waves and currents, or by a landslip assisted by these, but caused principally by springs of water. Wet weather succeeded by frosts, and other atmospheric changes, also cause the cliffs to fall, but to a more limited extent. When thus brought within the influence of the waves, the soluble parts are quickly removed by the waves and tides, and deposited where the water is quiet, the stony parts being alone left to form the beach, where they are subjected to the accumulative, destructive, and progressive action of the wind-waves.

The accumulative action tends to protect the cliffs from further encroachment by heaping the shingle against them; but there is only one case where it deposits the shingle in its final resting-place; —when the progressive action ceases, as at the Chesil Beach, and at Dungeness.

The destructive action appears to be very important where there is deep water adjoining the coast. It seems probable, that in such cases, by drawing out the material to form a foreshore, this action is most instrumental in preventing any beach from lying against the adjoining cliffs. The violence of the waves and the hardness of the cliffs being similar, it would appear, that with deep water immediately adjoining, this destructive action would be most effective in the process of encroachment; the material from the cliffs arriving, in that case, more expeditiously at a state of rest. It should, however, be observed, that deep water is thus kept, in some cases, by in-shore tidal currents moving the material, so drawn down by the destructive action. But when there is a long flat foreshore in front of the beach, this destructive action does not perform so important a part; as it is counterbalanced by the accumulative action at low water, there being in fact comparatively equilibrium.

The progressive action is, in this latter case, the most important;

by it the shingle is driven along the coast in both directions, but chiefly in the direction of the prevailing and most violent winds.

By all these three actions the materials from the cliffs are broken up, rounded, and ground to sand. Shingle under the progressive action being carried along the coast, is sometimes heaped against a projecting headland; which can only form, however, a temporary barrier. If it stands out into deep water, it causes the destructive action to be brought into operation for a long time before such a foreshore is made, that a beach can be formed at the point, so that the progressive action can drive the shingle onwards round it. In cases of such obstructions, both accumulative and destructive actions seem to be considerably increased in intensity, and there very generally exists a tidal current, or race, which, by removing part of the shingle, facilitates the destructive action. Estuaries and the mouths of rivers also form barriers to the progressive motion of shingle. In some cases, it falls into them below the action of the waves, in others it is carried into deep water by the flux and reflux of their tides. In cases where the mouths of the estuaries are deep and the tide sets fairly into them, a destructive action is, most probably, the consequence of the flow of the tide, the shingle, &c. being rather drawn into the deeper water; but where a bar is formed across the mouth, the tide passes up the estuary, or river, in the form of a wave of translation, carrying with it sand, &c. with which it forms shoals. Even in the former case, as the wave passes up the estuary, its character at a certain point, (probably where the bore begins,) is changed, after which it becomes accumulative, throwing up sand-banks, &c. It is important to observe, that the accumulative and the progressive action rarely bring shingle to a state of rest, they are only means to the end, whilst the destructive action, on the contrary, does pull it down into deep water below the action of the wind-waves. Not, however, to be there, in all cases, in a state of rest, for the tidal wave, in its various forms commences its operation.

Now the tidal wave seems to be subject to the same laws as other waves; when meeting with an obstruction to its course, its force is expended upon it. The rippling of the water at the 100 fathom line at the entrance to the English Channel, together with the sudden deepening of the water there, seem to indicate that line as the extremity of the foreshore formed by its destructive action, which action appears to continue up the entire length of the Channel, drawing down the materials to its mouth.

The tidal accumulative action is frequently to be found on the coast of France, for instance, the large sand-banks at Mont St. Michel,

or at the mouth of the Seine, &c. The sand-banks in the North Sea also appear to be the result of this action; as do also, to a great extent, the sand-banks formed up rivers and estuaries. The instances of this action of the tidal wave are, necessarily, few, from the fact of the tidal wave rarely expending its force on a coast, at right angles to its direction.

The progressive action of the tidal wave, however, plays a most important part by carrying within the operation of the destructive action, the materials which the wind-waves have formed into shingle, and carried within its sphere of operation. This tidal progressive action is observed, whenever there are waves of translation due to the accumulation of the tidal waters against projecting coasts, forming races, which carry the material brought within their reach into mid-channel. The peculiarity of these waves of translation,—that the velocity of the water during their transmission is the same at the bottom as at the surface,—is most important; it will easily be perceived, that water moving at a velocity of six miles, or eight miles an hour in a column 30 fathoms deep, must have a great effect of translation and corrosion on the bottom; the size of the material which the water at that depth would carry, being much greater than water at the surface, with like velocity, would be moved. By this progressive action is explained the position in which shingle, stones, &c., lying off headlands are found, also the formation of deeps, &c., in the line in which races set, and of banks beyond the sphere of the action of these races.

The Author terminates this Paper with the expression of a hope, that it may direct the attention of those who are engaged in Engineering works round the coasts to the subject, and that it may lead others, better able than himself, to consider the general action of the tidal waters, &c., so that sound principles may be ascertained for guidance, in executing future works, which from the variety of opinion at present given in the same cases, seem to be much required.

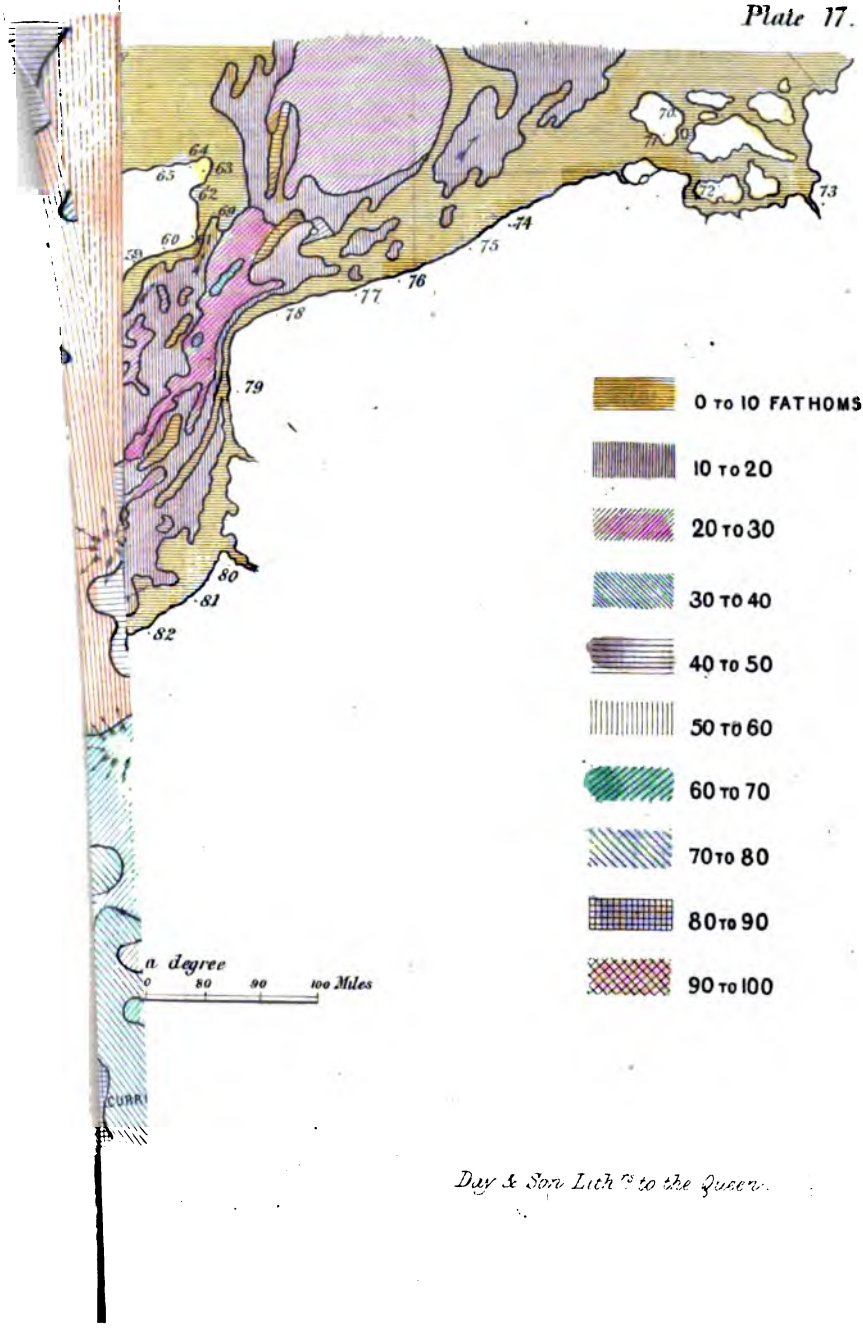
The Paper is illustrated by several charts of the English Channel, from which Plates 17 and 18 have been compiled.

APPENDIX.

TABLE, showing the TIMES of HIGH WATER on FULL and CHANGE, and the RISES of SPRING and NEAP TIDES, in FEET, at the under-mentioned places.

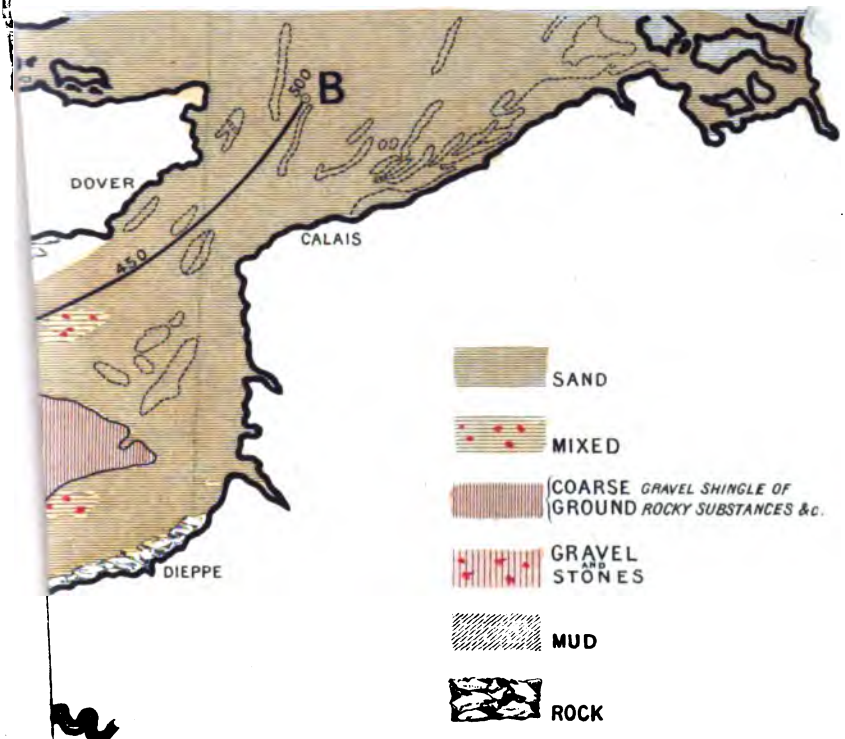
Number Marked on Plate 17.	Names of Places.	Time of High Water, on Full and Change.	Rise of Spring Tides, in Feet.	Rise of Neap Tides, in Feet.
1	Bantry Bay	3·45	11	5
2	Cape Clear	4·0	11	7
3	Baltimore	4·0	11	7
4	Castlehaven	4·0	11	7
5	Courtmacsherry Bay	4·15	11	7
6	Kinsale Harbour	4·30	11	7
7	Mumbles Point	6·10	..	..
8	Swansea	5·56	30	15
9	Nash Point	6·15	33	17
10	Cardiff	6·37	38	21
11	Chepstow	..	60 to 70	..
12	King's Road	6·50	48	29
13	Flatholm	6·35	..	..
14	Steepholm	6·37	38	21
15	Bridgewater Bar	6·50	35	18
16	Minehead	6·30	35	18
17	Ilfracombe	5·45	35	18
18	Barnstaple	5·30	25	12
19	Lundy Island	5·15	27	18
20	Padstow	5·10	35	18
21	St. Ives	4·55	35	18
22	Land's End	4·45	..	..
23	Mount's Bay	4·40	..	..
24	Lizard	4·55	..	..
25	Scilly Isles	4·40	18 or 20	..
26	Falmouth	5·15	18	12
27	Fowey	5·15	17	8
28	Plymouth Sound	5·20	15	8 or 9
29	Hamoaze	5·30	..	..
30	Bigbury Bay	5·55	..	..
31	Bolt Head	5·55	..	..
32	Start Point	5·58	..	..
33	Dartmouth	6·5	18 or 19	10 or 11
34	Torbay	6·0	..	..
35	Exmouth	6·25	14	8
36	Topsham	7·5	..	..
37	Lyme Regis	7·5	13 or 14	5 or 6
38	Portland Roads	6·30	6 or 7	2 or 3
39	Weymouth	6·30	..	..
40	Poole	9·0	6	4
41	Christ Church	8·50	6	4
42	Needles	8·56	7½	5
43	Lymington	10·15	12	8
44	Calshot Castle	11·55	..	..
45	Southampton	11·55	13	7
46	Cowes	11·15	..	..
47	Ryde	11·30	..	..
48	Dunnose	8·56	..	..

Plate 17.



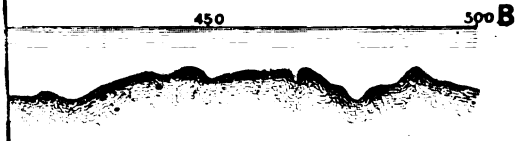
Day & Son Lith.rs to the Queen.

Plate 18.



Scale of Geographical Miles. 60 to a Degree

0 5 10 20 30 40 50 60 70 80 90 100 Miles



London, Day & Son Lith.rs to the Queen

Table showing the Times of High Water on Full and Change, &c.—*continued.*

Number Marked on Plate 17.	Names of Places.	Time of High Water, on Full and Change.	Rise of Spring Tides, in Feet.	Rise of Neap Tides, in Feet.
49	St. Catherine's Point	10·0	10	6
50	Portsmouth	11·30	16 or 17	11 or 12
51	Chichester	11·45	14	5 or 6
52	Selsea Harbour	11·45	14	5 or 6
53	Little Hampton	11·15	..	..
54	Brighton	10·5	..	..
55	Beachy Head	10.16	..	..
56	Hastings	..	22	14
57	Rye	10·36	..	..
58	Dungeness	10·30	24	15
59	Folkestone	10·45	15	9
60	Dover	10·50	15	9
61	South Foreland	11·5	..	..
62	Ramsgate	11·20	..	..
63	North Foreland	11·15	..	..
64	Margate	11·45	17	..
65	Reculver	11·30	17	..
66	Nore	12·30	14	..
67	Gravesend	1·30	16	..
68	Burnham	12·0	14	..
69	Downs	11·15	18	10 or 12
70	Veere	1·30	17 to 18	11 to 12
71	Flushing	1·20	13	10 to 11
72	Terneuse	2·0	..	..
73	Antwerp	4·25	13 to 14	11 to 12
74	Ostend	12·20	14 to 16	12 to 14
75	Nieuport	12·0	15 to 18	14 to 15
76	Dunkirk	11·55	16 to 19½	14 to 15
77	Gravelines	11·55	16 to 19½	14 to 15
78	Calais	11·30	15 to 18	8
79	Boulogne	11·8	.27	11
80	St. Valéry	10·30	..	..
81	Tréport	11·11	32	21
82	Dieppe	11·11	32	21
83	Fécamp	10·47	27	19
84	Havre	9·57	..	..
85	River Orne	9·45	25½	8½
86	Cherbourg	8·2	22	15
87	Alderney	6·45	33 to 39	19 or 20
88	Guernsey	6·30	33 to 39	19 or 20
89	Jersey	6·10	33 to 39	19 or 20
90	Mont St. Michel	..	45	..
91	St. Malo	6·5	45	..
92	Cape Fréhel	6·5	45	..
93	Bréhal	..	36	..
94	Morlaix	4·54	31	20
95	Ushant	3·46	21	..
96	Brest	3·48	..	..

Mr. GREEN said, that for forty years past, he had been well acquainted with the coast of Devon, and could confirm, from personal observation, the statements contained in Mr. Harrison's valuable Paper, with respect to the changes which had taken place, in the estuaries of the rivers, from the action and movement of shingle, and of the material forming the coast. The most remarkable case was that of the estuary of the Exe, which, according to very old maps, formerly had its sea entrance under Langston Cliffs, on the western side of the valley. The confluence with the sea was now very near the cliffs at Exmouth, more than a mile to the eastward of its former site. In the progress of this change, immense deposits of sand and silt, with some shingle, were made between Langston Cliff and Exmouth, forming what had for ages been known as the Warren, some parts of which were 10 feet above the level of high water of spring-tides, and extended towards the sea, more than a quarter of a mile beyond its present high-water line.

A great alteration had also taken place in the deep-water channel of the entrance of the river, which, forty years ago, was less than half its present width, and was much deeper; the decrease of the depth of this channel appearing to be in the exact ratio of the increase of its width. The Warren had not only been very much diminished in width, but so much in height also, that, about the year 1824, the sea broke over and nearly through it. The neglect of timely precautions to preserve the Warren, and the course of the entrance channel, he thought, would, in a short time, ruin Exmouth as a sea-port.

The Axe was of a very similar character, although it could now scarcely be considered an estuary, as the marsh lands within the bank of shingle on the shore, over which the tide formerly flowed, had been so contracted, as to leave only a comparatively narrow and uniform channel for the river. The accumulation of shingle had been such, as almost to close up the entrance to the sea; and it was with difficulty, that a sea-going vessel of comparatively small tonnage could now enter a small harbour, or basin, constructed within the line of the shingle bank. There, as in the Exe, the entrance had been driven from the western to the eastern side of the valley.

The mouth of the Sid was less accessible than any other river on the coast, for it was a rare occurrence to see any stream at all, running through the outlet, the water usually escaping merely by percolation through the loose shingle.

Very little change had taken place at Dartmouth, and other

places to the westward, as the rivers were chiefly mountain streams, passing through rocky defiles.

Mr. J. F. BATEMAN had not an intimate knowledge of the coast, mentioned in the Paper, but he had recently visited it, and had observed, that those estuaries which were wide above, and contracted at their embouchure into the sea, so as to receive with the flow, a large body of water, to be returned with force at the ebb, retained a deep and free channel; but that, as in the case of the Exe, when the width increased seawards, the scouring power was lost, and the channel became choked. The Sid was completely choked by a bar of shingle, so that no stream was perceptible, the water percolating through the shingle.

Mr. J. T. HARRISON said, that a portion of the island in front of the Warren, was visible in 1824. The surveys made within very recent periods by Mr. Whitaker, showed that the decrease of the Warren itself was very extensive; indeed, unless some means were adopted for checking the washing away of the sand and shingle, of which the Warren was composed, the whole would, in his opinion, be destroyed within a comparatively short time, and be spread over the bottom of the channel.

Mr. RENNIE eulogized both the subject of Mr. Harrison's Paper and the manner of treating it, and he urged the Members of the Institution individually, to bring before the Meetings, either by means of Papers, or at the discussions, the results of their observations upon the works to which their attention was constantly directed; if they would do this, an invaluable collection of facts would be made.

He had paid particular attention to the action of the sea on banks, such as the Chesil Bank, and he had noticed, that the material always formed that slope at mean and spring tides, which was most calculated to withstand the action of the waves. The amount of the tidal action must be kept in view; as the slopes which would be formed by the tides in Holland, would be very different to those on the coast of England, where the rise was so much greater.

The question of the translation of shingle was most interesting, when the examples of the obsolete harbours of Rye and Old Sandwich were considered, and the filling up of the channel which once separated the Isle of Thanet from the main land. The reasoning of Mr. Harrison on the causes of similar changes was most interesting, and he hoped the subject would be not only fully discussed, but would be recurred to by other Engineers, so that the Institution might possess a series of observations throughout the whole coast.

Mr. BEARDMORE observed, that in the remnants of forests occur-

ring at the low-water level, along the coasts of Devon and Cornwall, there were undoubted proofs of the land having been depressed, at some comparatively recent period: any theory of the tide having risen, at some period, far higher than at present, would not altogether meet the case. His impression, from a long acquaintance with the coast of Devon and Cornwall, was, that it had been subject to alternate elevations and depressions; indeed, the case of Exmouth appeared to indicate something of the kind, as the Pole Sand, situated outside the Warren, (now a half-tide bank,) had been inhabited within legendary, if not historical, record. The lowering, or removal of this sand, with the breach made in the Warren by the gale of 1824, had exposed the point on which the lower part of the town of Exmouth was situated: this being composed of sand, drifted by the wind, readily yielded to the tidal current, and had for some years past, given the landowners there much trouble and expense.

With respect to the Chesil Bank, it must be borne in mind, that geologically speaking, it had merely a coating of shingle, the substance of the bank along the portion which forms a barrier between the East and West Bays, being composed of beds of clay, occasionally having oolite boulders and fine running sands. It would thus appear in a very different point of view, than if it were formed entirely of shingle, like the outstretching headland of Dungeness. The circumstance of the large stones on the Chesil Bank, lying to the eastward, had been strongly insisted upon by some writers; but this was obviously the result of the heavy action of the rollers from the west, which carried all before them, whilst the rollers setting from the eastward, with less frequency and with far less violence, carried back the smaller shingle and left the larger *in situ*; giving an example of a sort of 'screening' on a great scale. It must be also remembered, that any idea of shingle travelling past the Isle of Portland, was fallacious; as might be readily observed, by inspecting the Admiralty chart of Weymouth Bay, which contained every evidence to the contrary.

He thought, that the Engineer should not look to mere tidal action, for the greater changes in the British harbours; it was the action of extraordinary tides and storms, united with other grand operations of Nature, which produced the effects described by the Author of the Paper.

Mr. J. T. Harrison said, that with respect to the conveyance of materials by the wave of translation, it must be borne in mind, that the effect was frequently aided by a strong current running in-shore, (as, for instance, from the Bill of Portland,) which, in certain states of the wind, carried a large quantity of shingle, and deposited it

directly upon the Chesil Bank. The same agencies conveyed large quantities of shingle from the coast into mid-channel, changing the formation of the bottom, as had been described in the Paper.

He must state, in reply to Mr. Beardmore's remarks with respect to the mouth of the Exe, that the hillocks upon the surface of the Warren, were certainly formed of 'blown,' or drifted sand; but that the substance of the land, up to and for some feet above high-water mark, was entirely shingle, perhaps rather finer, but certainly similar to the shingle, now composing the beach.

As to the traces of submarine forests, which, it was contended, proved the subsidence of the land, it was partly the object of the Paper to show, that these submarine forests, as well as the raised shingle beaches, were the result of variations in the level of the tides, consequent upon alterations in the contour of the coasts. There was a remarkable instance of this in the Great Western Bay. At the mouth of the Char, near Lyme Regis, slight remains of a submarine forest were found, whereas none were found in the estuaries of the bay to the westward.* Now according to the argument Mr. Harrison had used, this showed, that the tide rose formerly, at the mouth of the Char, to a less height than at present; whereas in the other estuaries, it rose to a greater height, as was evidenced by the raised beds containing shells, similar to living species, now found in the estuaries below. If the Char emptied its waters between Weymouth and Portland, (as it was conjectured to have done,) it would have had a much less rise of tide than at present; the rise of tide at Weymouth being only from 2 feet to 6 feet, whereas at the mouth of the Char, it now rose from 14 feet to 18 feet.

Mr. Scott Russell was glad to find, that Mr. Harrison had noticed the power of translation of the tide-wave, as an important element in the forces which were continually changing the configuration of the coast, and the condition of estuaries and navigable rivers. Mr. Russell coincided with Mr. Harrison in considering the tide as a wave of translation: he had always taken that view of its constitution. He had no doubt whatever, that every change in the configuration of the shore might produce a change both in the height of the tide at that place, and also at a great distance from it. The height of the tide, which at one time was so great, as to overflow an extensive district of country, might, at another time, be so acted upon by the changes of form of the coast,

* *Vide* Sir H. De la Bèche's Report on the Geology of Devon, Cornwall, and West Somerset, page 417. London, 1839.

that the range of high water might become extremely small. In this way, one part of the coast might, at one time, be covered by high water, and at another time, remain uncovered, without any change in the level of the land, so covered, or uncovered; but simply by an alteration of the range of the tide, which alteration of tide might be produced, by some change of the form of the coast at a remote place.

Mr. Scott Russell gathered from the Paper, that Mr. Harrison did not altogether agree with his views of the constitution of the tide-wave. Mr. Russell considered the tide-wave as a compound wave of the first order, because it was a wave of translation, agitating the water equally at great depths and near the surface; whilst the wave of the second order, with which Mr. Harrison assimilated the tide in the deep sea, was of a kind of which the translative action diminished rapidly, as the depth increased. Mr. Harrison, on the contrary, considered it right to call the tide-wave, a wave of the second order, because its particles oscillated alternately in opposite directions. This, however, was little more, perhaps, than a verbal difficulty which he had always felt, and he was not, therefore, dogmatic on the point.

Mr. Russell then briefly stated his reasons for considering the tide-wave as a compound wave of the first order; notwithstanding that it consisted of two parts,—a positive, or elevated, or plus part,—and a hollow, or minus part following. He considered the original form of the tide-wave, as due to extraneous forces, rather than to intrinsic forces. It was the peculiar nature of the action of the attraction of the sun and moon, which determined the original form of the great tidal wave of the ocean. All Mr. Russell's observations tended to show, that after the great tidal wave had been generated in the Southern Sea, it moved northwards, in conformity with the law of propagation of a wave of the first order. It consisted of a positive wave, succeeded by a negative wave, and on coming into shallow water the positive part moved faster than the negative, and the form of the wave became changed, in conformity with the law of a wave of the first order. He thought that there were, on the whole, more powerful and numerous reasons for considering the tide-wave as a wave of the first order, than as a wave of the second order, especially in cases where it had to be considered as a mechanical agent, acting on the bottom of the sea; a purpose for which it was most effective, and to which Mr. Harrison had very successfully applied it. As they both agreed on the facts and principles, and merely differed on the terms to be used, he thought it unnecessary to carry the argument further.

He perfectly agreed in the suggestions for the protection of the navigation of the Exe. He might state generally, that the principle which should be kept in view, in the improvement of channels and estuaries, was, to consider the flood tide in the character chiefly of a wave, and as such to promote its entrance, chiefly by increasing the mean depth of the channel. The ebb tide on the other hand, should be considered merely as the ordinary process of a full basin, emptying itself in conformity with the ordinary laws of streams, or running waters. This distinction was important enough to prevent many errors in practice. On the whole, he could not omit to unite his thanks to those of the Meeting, for the very important results of observation presented in the Paper, and to express his sense of the excellent manner in which the principles of the motion of waves were applied to the explanation of observed phenomena, as well as of the sound judgment with which practical conclusions had been drawn from the whole investigation.

May 9, 1848.

JOSHUA FIELD, President, in the Chair.

The remainder of the Paper, No. 786, "Observations on the Causes that are in constant operation tending to alter the Outline of Coasts, &c.," by Mr. J. T. Harrison, was read, and the discussion upon it was extended to such a length, as to preclude the reading of any other communication.

May 16, 1848.

JOSHUA FIELD, President, in the Chair.

The discussion upon the Paper, No. 790, "Observations upon the Resistances to Railway Trains, at different Velocities," by Mr. Daniel Gooch, being resumed, was extended to such a length as to preclude the reading of any other communication.

May 23, 1848.

JOSHUA FIELD, President, in the Chair.

The discussion upon the Paper, No. 790, "Observations upon the Resistances to Railway Trains, at different Velocities," by Mr. Daniel Gooch, being resumed, was extended to such a length as to preclude the reading of any other communication.

May 30, 1848.

On this evening, a Conversazione was given by the President to the Members and a large number of visitors; on which occasion, an interesting collection of Models of Engineering Construction and specimens of Works of Art, was exhibited in the rooms of the Institution.

June 6, 1848.

JOSHUA FIELD, President, in the Chair.

The following Candidates were balloted for and duly elected: Edward Humphrys, as a Member; Arthur Beanlands, Charles Frederick Cheffins, Thomas Duncan, William Haywood, James Newlands, and John Taylor, as Associates.

The discussion upon the Paper, No. 790, "Observations upon the Resistances to Railway Trains, at different Velocities," by Mr. Daniel Gooch, being resumed, was extended to such a length as to preclude the reading of any other communication.

June 20, 1848.

JOSHUA FIELD, President, in the Chair.

No. 796.—"On Harbours of Refuge."* By the Right Honourable the Earl of Lovelace, &c.

In the year 1836, a Committee of the House of Commons, after a lengthened investigation of the causes of shipwreck, reported, that, during the three years ending in 1818, eleven hundred and fourteen vessels were stranded and wrecked; and that in the three years ending in 1835, the number was fifteen hundred and seventy-three, besides one hundred and twenty-nine lost, or missing.† As each ship, with its cargo, was, on an average, computed to be worth £5,000, the annual loss to the shipping interest, during this period, amounted to £2,836,666; and what is of greater moment, seventeen hundred and fourteen persons belonging to the wrecked and stranded vessels

* The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

† *Vide* Report from the Select Committee of the House of Commons appointed to inquire into the causes of the increased number of shipwrecks, with a view to ascertain whether such improvements might be made in the construction, &c., of merchant vessels, as would diminish the annual loss of life and property at sea. Folio. London, 1836.

perished; or, including those on board the lost and missing ships, which have never been heard of, the country has been yearly deprived of eight hundred and ninety-four of her hardest-working sons and most able defenders.

Ten separate causes were assigned, and it is singular, that the want of harbours was placed last but one in order and in importance, in the judgment of the Committee, who thus enumerated them:—1st. Defective construction; 2nd. Defective equipment; 3rd. Defective repair; 4th. Improper stowage of cargo; 5th. Improper form; 6th. Incompetency of masters; 7th. Their drunkenness; 8th. Operation of the Marine Insurance; 9th. Want of Harbours; 10th. Want of charts.

In three gales of wind, in the years 1821, 1824, and 1829, one hundred and sixty-nine vessels were lost on the coast, between the Humber and the Tees. Of these, seventy-three were on the Redcar Sands, where it is said the greatest facilities exist, for the construction of a harbour. In 1836, thirty-nine vessels went on shore at one time in Holyhead Bay.

The subject necessarily continued to attract attention, and in the year 1843 a Committee of the House of Commons was again occupied with it. In the interval of seven years, that had elapsed since the first Report, circumstances had occurred to impair the *entente cordiale*, which had subsisted for many years between England and its maritime neighbour and rival, France. The possibility of a rupture, followed by a destructive war of naval aggression, in which the coast and commerce would require other defences and precautions, than those which had insured the national independence in the previous struggle, could not be mistaken. However ardently the continuance of peace might be desired, it was felt not to be so secure as formerly, and, moreover, that being fully prepared for defence, was perhaps the surest mode of averting any attempts to interrupt it, by disappointing the hopes and expectations of the partizans of war in that country, in which, more than in most others, a probability of success in what is undertaken, is an indispensable element.

The Committee of 1843 naturally desired to have the opinion of the Duke of Wellington, whose duties, as Lord Warden of the Cinque Ports, had led him to the frequent consideration of what would be the effect of a war with France, on the trade passing the coast of Kent. The Duke, in his evidence, pronounced himself strongly in favour of harbours of considerable extent, capable of sheltering some hundred sail of shipping at a time, both at Dungeness and at Dover, remarking, with his usual practical sagacity,

that "the French have the sun at their backs, while all our coast is light; they can, therefore, thus see when to sally out and pick us off;" and it would be, he urged, essential for the trade of London, to be able to make the passage in safety, without the inconvenience of waiting for a convoy. The Duke likewise drew attention to the distinction between a naval war, conducted on the old principle, and maritime war, such as would be resorted to in future contests, since the adoption of steam. It is unnecessary to dwell on the weight due, in a matter of this kind, to the thoughtful experience and opinions of the Duke of Wellington.

For annoyance of this description, the French possess much facility. During a course of thirty miles between Dungeness and the Goodwin Sands, a vessel running up in the fair way of the Channel, would be within fifteen, or sixteen miles of a point, (Gris-nez), between Boulogne and Calais, from whence she might be observed, and signals might be made to privateers and steamers, to steal forth and intercept her. The number of ships passing is so large, that a delay of a week, or two, to form and arrange a convoy, would produce an inconvenient accumulation of vessels, whose line of march and order of sailing, must necessarily be very tedious, since it would be regulated by the pace of the dullest sailers, and unless the fleet were convoyed by a tolerable proportion of men-of-war steamers, stragglers might be cut off by the enterprise of the enemy.

Two separate objects, then, are to be combined as much as possible: safety from the weather, and defence against the enemy. The former it has been proposed to accomplish, by means of floating breakwaters, for which, in the published Reports, there are numerous ingenious expedients, less expensive, it is true, than the fixed erections of rubble, or masonry, but also inadequate for producing still-water, uncertain in their duration, or in the reliance that can be placed upon them, and, for the most part, wholly incapable of defence from the shore.

Two of these inventions are large frames, or gratings, from 60 feet to 100 feet long, which are proposed to be anchored, or secured by Mitchell's screw moorings, in such a continuous line, or sweep, across the direction of the principal winds and seas, as to inclose an area of comparatively quiet surface, in the midst of the raging waters. In practice, however, there are great difficulties in the way of carrying out these theoretical views. The gratings must be moored near enough to each other, to prevent a free passage of great waves between them, and yet not so near as to allow them to be wrecked, by beating against each other. For the same reason, to prevent their grounding and being dashed to pieces, by striking against the

bottom, their lower extremities should not be within 10 feet of it, at low-water of spring-tides. The play then must unavoidably be considerable, since there must be space and cable enough, to allow for the utmost difference between high and low water, so that the flood shall not raise the floating structures a-peak above the anchors, or the ebb, by veering too much cable, permit collision between them.

Captain Taylor's method, as detailed to the Committee in 1843, and since carried into operation off Brighton, was to moor these gratings, in what may be called alternate échelons, the inner, or leeward line, being exactly opposite the openings, or intervals, between those in front: his frames were like large open crates, 65 feet long by 28 feet deep, to be immersed 18 feet; and at a cost, including chains and moorings, of £750 each, or about £12 per foot run.

Captain Pringle, R.E., proposed another kind, resembling huge field-gates, properly braced and ballasted, 100 feet long and 60 feet deep, at a cost of £700 each, or £7 per foot run.

A third sort, suggested by Captain Sleigh, R.N., was to be composed of floating caissons, whose decks and outriggers were to throw the waves and surf over them, producing comparative quiet within; but, besides the difficulty of providing against the upsetting of the caissons, from the violent efforts they would constantly make to escape from their anchorage, their depth appears to be scarcely sufficient to counteract the surging of the sea.

Another novelty was proposed by Major Parlby,* of the Bengal Engineers; his aim was to imitate a gigantic band of artificial reeds, growing in the open sea; and this he thought might be accomplished by means of hollow floating trumpets, 3 feet apart from centre to centre, so that a space 1,000 yards long, by 25 yards wide, would require twenty-five thousand of these trumpets, each several feet long, and secured by its respective cable, to large stones at the bottom, screw moorings, or other effective anchors. These trumpets were to be of coir, or cocoa-nut fibre, said to be indestructible in salt water, and coated with Indian rubber. A ship, it was argued, could enter this breakwater at any part of the line, either to windward, or to leeward, slipping smoothly in, through the yielding stalks of artificial weed.

The projectors of timber floating breakwaters, appear to have

* *Vide* First Report of the Select Committee of the House of Commons appointed to inquire into the shipwreck of British vessels, and the means of preserving the lives and property of shipwrecked persons, and to whom the Reports of 1836 and 1839 were referred; together with Minutes of Evidence, Appendix and Index. Folio. London, 1843. p. 244.

hardly calculated, either the strength of their structures, or of the moorings required to keep them in their places, and without which they are of course worse than useless, acting as mere decoys and traps to entice vessels to enter; for if they afterwards break loose, they would, by collision, cause the destruction of a fleet, sheltered beneath their lee. Yet this is not an improbable result.

There are 2,000 cubic feet of timber, in Captain Pringle's breakwater; a transverse section of the immersed portion of it, would give the equivalent of about 2,000 superficial feet, exposed to the full action of the sea, and secured by two anchors. Now a line-of-battle ship would rarely anchor, in so exposed a situation, during such a gale as this breakwater is intended to resist; but if she did, she would have her bower and sheet down, and in her emergency she might shackle on an additional length of chain, to the full cable she had already paid out, and even then, with 10 tons of anchors,* and all the *vis inertiæ* due to 300 yards, or 400 yards of chain cable, it is doubtful whether she would not drive. Yet all this would be employed, in detaining a body of from 600 to 800 square feet of transverse section; for such is the transverse sectional area of her immersed part. Making, then, every allowance for the action of the wind upon the hull and rigging, it seems hopeless to expect, that short moorings can be found to secure the 2,000 feet of the breakwater, while whole cables' lengths and powerful anchors, fail to hold the comparatively small area, presented by a ship. It may be said, that the timbers of the gratings may be disposed lozenge-fashion, to divert the water and lessen its impact. It is, however, the same with the vessel, whose bow is more, or less, constructed to turn aside the waves, and it is probable, that the same fate as that which befel Captain Taylor's scheme, would, sooner or later, overtake similar attempts elsewhere. They are, besides, indefensible from the shore, or indeed by other means, than that of men-of-war properly stationed to protect them; and within sight of the coast, an enemy might run in and take possession of whatever suited him there; or in case a sufficient number of vessels should have run inside, the barrier might be forced to windward, by the sacrifice of a vessel, or two, and the whole fleet of merchantmen be destroyed by fire-ships.

It is not, therefore, surprising, that these projects met with little encouragement, from the parties before whom they were produced.

In April, 1844, Sir Robert Peel's Government issued a Commis-

* There are to be four anchors, but only two would act at the same time; two having a fore-and-aft action, while the other two are athwart-ships.

sion, to several naval and military officers and civilians,* to report, first, whether a harbour of refuge in the Channel was desirable, considering its cost and its advantages; and next, what should be its site, combining in the greatest possible degree the three requisites:—1st. Accessibility, at all times of the tide, to vessels requiring shelter from stress of weather. 2nd. That it should be calculated for a station for armed vessels, in the event of hostilities, both for the purposes of offence and defence. 3rd. That it should possess facilities for securing its defence, in the event of an attack by the enemy. In case the Commissioners should be of opinion, that all these objects could not be secured by a single harbour of refuge in the Channel, they were to extend their inquiries, and to report their opinion of the peculiar advantages, of each of the several situations they might recommend, and to which, on the whole, they might give the preference.

On the 7th August, 1844, the Commissioners presented their Report.† The places which mainly invited their attention, were Foreness, Ramsgate, the Downs, Dover and Dungeness, Beachy-head, Eastbourne and Seaford, Newhaven, Portland, and Harwich. They arrived at three distinct conclusions, recommending, first in expense and importance, a harbour of 520 acres at Dover, then one at Portland, next Seaford, and lastly Harwich. To this there was one dissentient voice, that of Sir William Symonds, who considered Dungeness preferable.

The most considerable of these sites is Dover, from its position and the relation to the number of shipping constantly passing it, as well as the cost proposed to be incurred. After much and most conflicting evidence the Commissioners recommended a harbour, with an opening of 700 feet in the south side, and a similar one at the eastern end.

The problem to be solved is one of no ordinary degree of intricacy and doubt; for, in the language of one of the witnesses, there are three sorts of harbours:—1st. Breakwaters, or natural inlets from the sea, as Portsmouth and Plymouth; 2nd. Channel harbours, as Spithead and the Motherbank; 3rd. Close ports, such

* Admiral Sir Thomas Byam Martin, G.C.B.; Lieut.-General Sir Howard Douglas, Bart., G.C.B.; Rear-Admiral Deans Dundas, C.B.; Sir John Henry Pelly, F.R.S., Deputy Master of the Trinity House; Captain Sir William Symonds, R.N., F.R.S., Surveyor of the Navy; Captain John Washington, R.N., F.R.S.; Lieut.-Col. Colquhoun, R.A., F.R.S.; Lieut.-Col. Alderson, R.E.; Captain Fisher, R.N.; and James Walker, Esq., F.R.S. L. and E., M. Inst. C.E.

† *Vide* Report of the Commissioners on the subject of Harbours of Refuge. Folio. London, 1845.

as Kingstown and Howth. The first of these often labour under the objection of bars, and the last are liable to silt up, from the stillness of their waters, whilst those having a tideway working through them are obnoxious to none of these disadvantages. Accordingly, some of the scientific witnesses who were examined, insisted strongly on the necessity of an open harbour, covered by a breakwater unconnected with the shore, and whose longitudinal disposition, in the same plane as the tidal current, would afford a free scour, throughout its extent.

The disadvantages of this plan are, that in proportion to the width of the opening, so does it admit the sea to disturb the shipping, the strain on whose cables is still further increased, as the tidal stream runs past them, with more, or less velocity, and in the particular case of Dover, there is the additional difficulty of the shingle to contend with. If then a large eastern entrance is determined upon, there will probably be considerable movement in the harbour, and a filling-in of the shingle, which is now constantly accumulating from the westward. If it is proposed to remove the mouth, so as to defend the entrance from the full volume of the sea, and at the same time to act as a groyne, or shingle trap, another dilemma arises; it is true, that the tidal current is admitted through this modified opening, but unless the stream be distributed evenly throughout the harbour, the turbid flood will begin to deposit, as soon as it gets into the comparatively still water within, and as in lakes, the entering current will, in its passage, gradually precipitate whatever matter it holds in suspension. The silt is, no doubt, a formidable enemy to the havens on this part of the coast; the tide running with tolerable velocity, along a shore abounding in chalk, or other equally soft material, liable to be abraded, and carried along by the action of the water. Before, however, fixing attention to the case of Dover only, it will be more convenient to notice some of the other views, brought before the Commissioners.

Captain Vetch, R.E., proposed the Downs. This open roadstead some eight miles, or nine miles long, opposite Deal, is sheltered by the Goodwin Sands to the north-west; and between Deal and Sandwich, the Brake Sands form an inner and more sheltered roadstead for smaller vessels. Captain Vetch's plan is to fix both of these sands, by an embankment, formed by driving down into the sands iron rods, or piles, one foot apart, arranged, in fact, something like a large bird-cage, 12 feet square, with a bottom of faggots and brushwood, to gather the sand. By this method, Captain Vetch imagines the Goodwin Sands would, in time, become an island of 8,000 acres, and the scour of the tides, through the Gull

Stream to the northward, would be advantageously increased. Captain Vetch was mainly anxious, for the improvement of the small Downs, by means of embanking the Brake, and the advantages of a great and costly work on the Goodwin, or outer sands, do not seem insisted upon by him, to an extent sufficient to justify a work of such enormous magnitude. On the Brake, the process of fascines and gabions would be the same, for a distance of above three miles, and in an average depth of 2 fathoms.

The idea of enclosing the small Downs, by artificially increasing the Brake, had been also entertained by Sir John Rennie, who was examined as a witness to that effect before the Committee of the House of Commons on Shipwrecks.* The length of the work would be four, or five miles, at a cost of £1,300,000. To the Ramsgate harbour-trustees, Sir John Rennie had given an estimate for the same work, for the sum of £3,200,000;† but this was on the supposition, that the sea was to do nothing,—art and labour everything; the smaller and later estimate, resting on the expectation, that nature was to do a large portion of the work, and pilots showed, that within the last forty, or fifty years, the Brake sand had moved bodily in-shore, nearly one-third of a mile.‡

The next place of importance is Portland. This island, or rather peninsula, of three, or four miles in length, is connected with the coast of Dorsetshire, by an isthmus of shingle, a mile and a half long, known as the Chesil Bank, which forms the Portland and Weymouth Roads, affording shelter from all winds from N.N.E. to S.S.E. by W.; (should the wind, however, chop suddenly round to the East, vessels at anchor in the roads run the risk of being driven ashore.) Owing to this, and its situation nearly opposite Cherbourg and the Channel Islands, the Commissioners have recommended the formation of a breakwater, a mile and a quarter long, sheltering 1,200 acres, at a cost of £500,000. Portland has, they observe, great advantages, abundant springs of fine water, which may be had in any direction, for the expeditious watering of

---

* *Vide* First Report of the Select Committee of the House of Commons, appointed to inquire into the Shipwreck of British Vessels, and the means of preserving the lives and property of shipwrecked persons. Folio. London, 1843. p. 375.

† *Vide* Minutes of Evidence taken before the Commissioners on the subject of Harbours of Refuge. 1844. p. 27.

‡ Mr. R. Stuart, a pilot at Woolwich, was sure that, in the last fourteen, or fifteen years, it had drifted westward 700 yards. Mr. Clerk, a Cinque Ports Pilot, had observed the same. *Vide* Minutes of Evidence, &c., Harbours of Refuge, pp. 14 and 48.

a fleet, a position intermediate between Torbay and Portsmouth, good holding-ground, and cheap, easy, and expeditious means of construction, from materials on the Crown property in the island. It has, indeed, been intimated, in the course of the inquiry, that the island should no longer be left unprovided with defence, and that an enterprising enemy once in possession of it, by a *coup-de-main*, might permanently establish himself on it, and convert it into a second Gibraltar, a contingency which a small fort, on its upper portion, would effectually prevent.

Harwich is an example of the changes gradually taking place on our coasts, partly from natural causes, and partly from the operations of men. On the eastern side of the harbour, which is formed by the estuary of the rivers Stour and Orwell, the beach under Landguard Fort, has expanded itself outwards, above a quarter of a mile, since 1804; and on the opposite, or Harwich side, the Beacon Cliff has been undermined and destroyed. The former encroachment, besides choking the channel of entrance into the port, threatens, by driving the sea over to the opposite shore, to wash down Harwich. In one part, where the Commission had information, that a few years ago a 74-gun ship had sailed out, there is now land and beach, 6 feet, or 7 feet above high-water mark.

The inroads of the sea are, however, greatly assisted by, (in this case,) the pernicious industry of men. The cliffs contain layers of cement stone, the collection of which occupies numbers of persons. They and the tides mutually aid each other; what the sea uncovers, man appropriates; what man has loosened, the sea effectually overthrows.

Since the peace, and the ready communication by means of steam, between London and the ports of the continent, Harwich has lost its importance, both as a station for the North Sea fleet, and for the packet service; the former consideration would, in the event of a war, insure steps being taken to dredge and deepen the entrance harbour.

Nunc tantum sinus et statio malefida carinis.*

It is now necessary to examine more immediately, the result of the inquiry instituted by the Commissioners, viz., the construction of a breakwater at Dover. After agreeing, with one dissentient voice only, that Dover was the right place, there remained to be shown, what was the best mode of sheltering the same; what should be the form and method of construction, and the materials to be

* *Vide* Virgilii Æneid. lib. ii.

employed; whether the breakwater should be unconnected with the shore, or joined to it; whether with several, or few openings: and to this task, the Commissioners applied themselves with great assiduity,* calling to their aid several of the most eminent authorities in mathematical science and in practical engineering, and availing themselves also, of the knowledge possessed on these matters, by the members of their own body. Their Report,† with the evidence on which it is based, contains an extraordinary collection of reasoning, well worthy the perusal of all who are engaged in the execution, or who are liable to the costs of hydraulic construction.

In their Report in 1845, the Commissioners had indicated the situation, extent, and position of the breakwaters they recommended. In the same autumn, the Admiralty referred to them, to examine and report on the different plans‡ that had been sent in, for the formation of the great work. These were eight in number; three of them proposed rubble constructions, like those of Plymouth and Cherbourg, and the other five recommended vertical walls, either of masonry, or concrete.

In January, 1846,§ the Commissioners decided in favour of an upright wall of masonry, rising from the bottom of the sea.

The two great evils to be apprehended at Dover were, the accumulation of shingle to the westward, and the general deposit of silt, all over the enclosed area. "I have seen,"‖ says Capt. Peat, R.N., commanding the Coast Guard at Folkestone, "from 100 tons to 500 tons of shingle, heaped up at each of these places, in a single gale of wind." This action is not peculiar to Dover. M. De Cessart states, that 40,000 cubic yards are annually washed into the

---

* For this purpose a second Commission was issued in September, 1845. The Commissioners appointed were: Admiral Sir Thomas Byam Martin, G.C.B.; Lieut.-General Sir Howard Douglas, Bart., G.C.B., F.R.S.; Rear-Admiral Deans Dundas, C.B.; Sir John Henry Pelly, Bart., F.R.S., Deputy-Master of the Trinity House; Captain John Washington, R.N., F.R.S.; Lieut.-Colonel Colquhoun, R.A., F.R.S.; Lieut.-Colonel Alderson, R.E.; Captain Beaufort, R.N., F.R.S., Hydrographer to the Admiralty; Captain Brandreth, R.E., F.R.S.

† *Vide* Report on the Harbour of Refuge to be constructed in Dover Bay. Presented to both Houses of Parliament by command of Her Majesty. London, 1846.

‡ *Vide* Reports and Plans for a proposed Harbour in Dover Bay. London, 1845.

§ *Vide* Report on the Harbour of Refuge to be constructed in Dover Bay, 1846. pp. vii. viii. ix.

‖ *Vide* Minutes of Evidence taken before the Commissioners on the subject of Harbours of Refuge, p. 55. London, 1845.

ports of Dieppe and Tréport, on the opposite side of the Channel. Accordingly, great anxiety is evinced by the Commissioners, to ascertain the probable amount of inconvenience, from this cause, and the best means of preventing it. Capt. Vetch, who is most apprehensive of the silting up, and who is aware, that large openings to the westward, for the purpose of permitting the full volume of the tide to roll through, must likewise admit the shingle, proposes to remedy this by running out a succession of groynes, or shingle-traps, as they might become necessary. The expense of this system, however, would be considerable, and it might indeed be just as economical, even if the probabilities of the anticipated deposit be admitted, to dredge the harbour, when it became too shoaly, than to resort to these expensive works.

Sir Henry De la Bèche thought,* "that the shingle would travel, that it might eventually reach the western entrance of the harbour, supposing there to be one at 200 yards, or 300 yards from the shore; but that it would be a long time first." The arresting of it, by means of the harbour, or breakwater itself, would of course depend on the direction given to the projection of the pier, its form, extent, and the depth of water in which it is situated. "From distance to distance, often considerable," observes Sir Henry De la Bèche, "beaches are often now arrested, not readily passing round some headlands: the drifted shingle there accumulating in the deep water; you could only arrest, to a very limited extent, the progress of such shingle in these distances, for if the supply be greater than your means of stoppage, it must necessarily accumulate and pass on."

Now Dungeness is a case in point, which will supply an illustration of Sir Henry De la Bèche's remarks. That low point running out from the Kentish coast, may be regarded as a natural groyne, serving to bring up and arrest the shingle, which has been washed along from the westward, where, close along the shore, at a distance of two cables' length from it, the depth is seldom less than 3 fathoms, at low water, and on sounding within that distance of the Ness itself, the water suddenly deepens to 10 fathoms and 15 fathoms; accordingly the increase, though steady and constant, is very slow, as the embankment is turned over into the deep water.

The increase seems to be about 6 feet, or 7 feet† to the south-

---

* *Vide* Minutes of Evidence taken before the Commissioners on the subject of Harbours of Refuge, p. 40. London, 1845.

† From indications on the spot, it is conjectured by Captain Washington, that the advance of the point seaward has proceeded at the same rate from a

ward, in a year, as appears from an inscription inside the light-house, which states that it was erected in 1792, at the distance of 100 yards from the sea. It is now 190 yards distant; five thousand, or six thousand acres of shingle have thus been formed, by this natural stoppage. Some of the shingle, however, appears to have been carried round the point, and deposited on the Roar Bank to the eastward. The tide runs with remarkable scouring power off the Ness. The Swallow Bank, three miles eastward, formerly a mile long, with only 16 feet of water upon it, is now but half a mile long and 22 feet below the corresponding level of the tide. The Chapel Bank, a like distance eastward, has been diminished from two miles to one mile, but the Roar Bank Sand, in the east bay, has been increased.

It appears probable, that a pier, or breakwater, projecting boldly from the shore, and at a right angle with it, to the distance of 600, or 700 yards, into 7 fathoms water, would form a sort of Ness at Dover, behind which the shingle might accumulate for ages; such a groyne would probably prevent anything from being swept round for an almost indefinite period, nor does it appear, that there could be any movement eastward, until the whole triangular area comprised between the shore for a mile in length westward, and the pier as a perpendicular to it, had been filled up with shingle, to the line of the hypothenuse, forming an extent of from 200 to 300 acres.

One of the witnesses being asked whether he would, with reference to this difficulty of shingle, prefer a sloping breakwater to an upright wall, replied, that a sloping breakwater would form a road for the shingle to travel upon. This remark appears very just; but it must be observed, however, that had the principle of a slope with loose stones been adopted, the shingle, working its way into all these interstices, would, in the first instance, be beneficial, as tending to bind and consolidate the larger stones. If the Plymouth Breakwater had enjoyed this advantage, it would have been far more secure and free from disturbance; but an insulated breakwater, rising, as that does, from a deep sea, never can receive such aid. When, however, all the cavities of the structure at Dover became full, the form of the slope would facilitate the passage of the shingle, and aid in whirling it round into the harbour's mouth, as it now travels into the present port.

---

remote period; calculating from the erection of the former light-house, in the time of James I., till its removal to its present site in 1792, his opinion is, that the shingle may have begun to accumulate at the foot of the present limits of verdure, (now 5,800 yards inland,) about the commencement of the Christian era.

The obstacles presented by the silt must now be considered. The amount held in suspension, depends partly on the fineness of the particles, their form, the force of the current, and the agitation of the sea. Sir Henry De la Bèche, from frequent observations in the course of his geological studies, thinks, that in heavy gales, the water acts upon and is discoloured by silt, to the depth of 15 fathoms. Some of the Commissioners suggest the possibility of removing it, by iron rakes, or by stirring the surface of the harbour by steamers towards low water, and inquire whether that would tend to keep it clear. Sir Henry De la Bèche* thinks it would depend entirely on whether there was a sufficient current to carry off the water, after it had been so agitated. Sir Henry, however, does not appear, from the general tenor of his evidence, to apprehend an enormous deposit, though he states, that all close harbours are, in some degree, liable to this objection.

Captain Vetch thinks the deposit will be large. He quotes Smeaton to show, that for eight years, about 30,000 cubic yards of silt had annually accumulated in Ramsgate Harbour; whilst he admits the difficulty of contending with circumstances, requiring two opposite remedies; for, if the tidal current is admitted, the shingle will enter also, and with it an amount of sea, sufficient to agitate the shipping.

In compliance with the wish of the Commissioners, Captain Vetch proposed a plan for an insulated breakwater 3,070 yards long, and nearly straight; the western portion, of 1,100 yards, pointing slightly inwards to Dungeness, and the eastern part towards the South Foreland, by which he expected to secure the full scour of the current throughout. There were to be projections from the shore, opposite each extremity of the breakwater. Captain Vetch agreed, that the southern face would not be directly exposed, to any formidable action of the sea; but that circumstance, however favourable to the stability of the work, would tend somewhat to defeat its object; since, if a heavy sea rolled along in the same plane, with free access at the mouth, it must cause the vessels inside to labour heavily, and to remedy this, two lozenge-shaped islands were to be placed opposite, but inside each of the entrances. These would modify the force of the sea, but they would probably cause slack water, and a deposit immediately behind them.

Professor Airy, in a Paper forwarded to the Commissioners, examined the probabilities of silting up, under the different con-

---

* *Vide* Minutes of Evidence on the Harbour of Refuge to be constructed in Dover Bay, 1846. Appendix 13, p. 87.

ditions of a through current and a single entrance. In the latter case, he says,* "only the tidal volume which belongs to the harbour surface, and no more, will enter and depart at every tide, depositing nearly the whole of its mud." But if there is an entrance to the eastward and one to the west, then a far greater quantity of water will pass through at each tide, and a large proportion of this, will have quiet enough to deposit its mud; and he thinks,† (30) in this latter case, the deposit will be much greater than in the former.

Professor Airy's attention having been directed to the possibility of stirring, he concluded, "that if there is no artificial stirring, a harbour with no through current, is more secure; if there is an artificial stirring, I think, (but not confidently,) that a harbour with a through current is more secure." With the plans of Captain Vetch's detached breakwaters, covering projecting jetties‡ (44), "there would be good depth in the through channel and perfect silting up with mud, in the angles af the jetties."

Captain Washington, R.N., a member of the Commission, was charged by the Admiralty, with the task of experimenting on the quantity of silt, held in solution by the water in Dover Bay.§ In his First Report of March 1st, 1845, he gave the result of several trials, and was inclined to think, that a cubic foot of the water contained, on an average, 33·8 grs., and, (assuming the mean range of the tide to be 15 feet,) the upper portion of the water being changed seven hundred and four times in every year, would, if it were evenly charged, deposit about 51 lbs. per annum on each square foot of the bottom; and as a cubic foot of silt weighs 103 lbs., this would equal a layer of six inches deep all over the harbour. However, in a Second Report from Captain Washington, dated 27th November, 1845, these calculations are considerably modified, and from two hundred additional observations, being nearly three times the number from which his first conclusions were drawn, he obtains an average of 17·5 grs. per cubic foot of water; that is, three inches of dry deposit, or five inches of wet soft silt for the surface of the harbour. It was also stated, that in consequence of the progress of the South Eastern Railway, involving the destruction of the chalk cliffs, the water at Dover was more than usually discoloured, during the period in which the first observations were taken.

---

* *Vide* Minutes of Evidence on the Harbour of Refuge to be constructed in Dover Bay. Appendix 15, p. 89.

† Ditto, ditto.

‡ Ditto, ditto, p. 90.

§ Ditto. Appendices 4 and 5, pp. 73, 75.

The expense of dredging, should that unfortunately become necessary, would be so great as to be only justifiable, from the importance of maintaining the depth in the harbour. But assuming, that a much larger deposit should occur, than Captain Washington has shown to be at all probable, it might be allowed to go on for some years, not only without injury, but to the advantage of the harbour. At least one-third of the proposed area possesses a depth of water, exceeding 5 fathoms over these 140 acres; and here until the water shoaled to a depth of less than 26 feet, it would be useless to dredge. The deposit of silt over the hard chalk, would be an improvement to the holding qualities of the ground, by permitting the anchors to bury themselves, and it is in the deeper water, that the deposit would chiefly occur, since, from its proximity to the entrance, it would just present that stillness to the entering flood, which causes it to part with its load. But supposing that there were 300 acres requiring the operation, the cost at Ramsgate of dredging and carrying away, is about 7*d.* to 8*d.* per cubic yard; five inches of silt left annually, would give about 200,000 cubic yards to be moved, and if 8*d.* per yard be allowed, it makes the cost rather under £7,000 a-year; a heavy item, no doubt, but light in comparison with the interest to be paid on the capital cost of construction of even the smallest of these projected harbours. After all, the silting up, to any extent, is by no means certain; Kingstown Harbour, in Dublin Bay, past the mouth of which the tide runs heavily charged, especially on the ebb, shows scarcely any tendency to silt; and as the projected pier at Dover, with only one main entrance in the south face, will occupy a somewhat similar position, there may be less inconvenience from this cause than was at first apprehended; but should it arise, the injury is evidently one which can be met and controlled.

Having thus far adverted to the question of silt, the more formidable one of construction remains to be considered. And, on this point, although in an enterprise so novel, a vertical wall of such dimensions, and in such a position, must be in a great measure experimental, there is reason for believing that the Commission have come to a just conclusion, notwithstanding the protest of Sir Howard Douglas. For though there are not wanting instances of breakwaters, composed of loose stones, in this and in other countries, which have more, or less, answered the purpose for which they were designed, yet it has always been after long delays, great cost, and heavy and constant repairs caused by their construction. The slope of four to one, intended to represent an angle of repose, is insufficient, to secure even the largest masses from displacement by the

waves. The whole mass is thus liable to perpetual disturbance, and the undertaking may be said never to be practically completed. The Breakwater at Cherbourg, commenced above sixty years ago, is still unfinished. Three times has it reared its head above the waves, and as often has it been overthrown and ruined by their onslaught; at last, from a conviction of the inadequacy of the rubble principle, it was determined, in 1833, to take it down to the low-water mark, and to raise from that level an upright pier of masonry. This has accordingly been executed on a concrete foundation, and its outer face defended by large masses of béton, connected with which was a foreshore of large blocks of stone, some of them weighing four tons each. Captain Washington, who visited the port, expressly with the view of ascertaining the value of the principle, observes, that, "notwithstanding these precautions, after fifty years from the first formation of the breakwater, on the 24th Dec. 1836, a heavy N.N.E. gale broke in upon it in all its fury. These very blocks were lifted by the waves, cleared the wall at a single bound, and upwards of two hundred of them were deposited on the inside of the breakwater." The masonry erected upon them, Captain Washington was informed, was rent in large cracks, not, as was at first supposed, from the shocks of the sea, but from the uneven settling of the rubble stones, on which the structure rested. This settlement, though not perfectly uniform, averaged 18 inches in 22½ feet, or about one-fifteenth of the whole height; nor is this surprising, when it is considered, that these masses have been dropped into their places, with nothing but their own weight, (one-third of which is lost in displacing their bulk of water), to settle them.

Mr. Rendel, who states his objection to the principle of the Plymouth Breakwater, observes, that there is 32 per cent. of vacuity, in consequence of using large stones; indeed there is even more, since every ton of 13 cubic feet, when deposited in the breakwater, has occupied 22, or 23 cubic feet; while in a pier, which he is now building at Mill Bay, where the entire quantity of stone excavated is made use of, without reference to size, the solidity has been ascertained to be as seventeen to thirteen.

The arguments in favour of the long slope, were strenuously urged by several Civil Engineers. Both Mr. Rennie and Sir John Rennie have naturally adopted the opinions of their late father, who resorted to the use of the slope, in projecting the Plymouth Breakwater, thirty-five years ago. Sir John Rennie is averse to the upright wall. Mr. Rennie supports the same opinion; he quotes the now somewhat antiquated and inconclusive document, published by the French Engineers in 1792, to the effect, "that the only means

of preventing the crest of the work from being disturbed, is to cover the entire construction with large masses of stone work, sufficiently solid to resist the waves;" and he adds, "that any departure from the system of Cherbourg and Plymouth would be a retrograde step in the path of science." It is difficult to comprehend how the substitution of solid masses of masonry, skilfully put together, and lowered into their appointed beds by powerful and exact machinery, and the arrangement of them by divers at 30 feet and 40 feet below the surface, instead of dropping in huge cyclopean fragments, to shake themselves into places as they best may, can be called a retrograde step in science. Mr. Rennie's argument appears to be, that it is necessary to imitate, artificially, that form which the action of the sea gives to beaches, which arrange themselves naturally at the angle best calculated for resistance. During the time, he says, that Kingstown Harbour was in progress, he had observed, that on the masses being thrown into the water, the stones took a long slope, like a glacis made by the hands of man.

The pier at Kingstown, which has a section similar to that of Cherbourg, is 103 yards wide at the base, and 18 yards at the top, and has the outer face roughly pitched with large stones. These have been repeatedly disturbed by the breakers, and have been replaced with still heavier stones, some of which are still washed away with every south-east gale. In thirty years it probably will have cost £800,000, and yet Colonel H. D. Jones, R.E., the Chairman of the Board of Works, in Ireland, says, that "it remains as insecure as heretofore."

Howth is another work of a similar construction; it has cost £500,000. The same action takes place, though not in so violent a degree; and now, on account of its silting up, it is of little use, except for fishing-boats.

Ardglass, County Down, was designed with a long slope of four to one, at an estimate of £20,000. The sea is constantly washing out the stone and bringing it into the harbour. A lighthouse was built on the pier, and, in 1838, a succession of easterly gales, (the mere sweepings of the Irish Sea, very different things from the fetch, up channel from the Atlantic,) "were sufficient to undermine the pile. Pier, lighthouse, and all, fell into the sea, where they now lie a heap of ruins."

At Donaghadee are two smaller piers, each 270 yards in length, inclosing between them a harbour. They are built on long slopes, and the opening is 56 yards across. On taking soundings in 1845, stones were found, which had been washed out of the sea slopes, and reaching half-way across the harbour's mouth. The sea is con-

stantly and successfully attacking the works, and the whole summer scarcely suffices to repair the damage done by the heavy gales, during each previous winter.

Portrush is another instance. It was arranged in 1826, with two piers, each above 200 yards long, with slopes of four to one, between the heads of which was an entrance 67 yards wide, with a depth of 20 feet at low-water spring tides. When the 'Blazer' steamed in, in September, 1845, the width of the entrance had been reduced to 43 yards, and she was stated to have skirted an artificial reef of rocks close on each side, arising from the débris of the glacis. "A yaw of the helm," observes the captain, "or an accident to her machinery, (for she ran in during a north-west gale), would have been inevitable destruction to the vessel."

Again, Dunmore Pier, County Waterford, is of the same description, the ruins of which have formed a large reef, 112 feet long, off the pier head, in the very place where a sailing-vessel, unless with a leading wind, requires the fullest room for working in and out.

The results of the long slope at Cherbourg have been already shown. The Plymouth Breakwater was commenced in 1811, chiefly from the design and under the superintendence of the late Mr. Rennie. Eight years afterwards a heavy gale and an unusual tide, overthrew a large portion of the finished work. The Engineers of that day, however, made the best of their misfortune, congratulated themselves and the public on the general settlement of the question, with the consolatory assurance, that no apprehension need be entertained of the recurrence of such an injury. So wrote Mr. Whidby to the Navy Board. On the 23rd Nov. 1824, another gale occurred, and two-thirds of the finished work were again overturned. On this occasion 200,000 tons of stone were moved from their places, and the slope, as left by the sea after this operation, was five to one on the southern incline. This, then, was adopted as the real angle of repose, at which matters were expected by Messrs. Chapman, Jessop, and Rennie, to remain in peace. The width at the top was increased from 30 feet to 45 feet, to add, (as Mr. Stuart expressed it,) to the stability of the work. Nevertheless, the conductors of the work appear to have had misgivings about its security, and, in 1830, they determined to deposit a further quantity of 600,000 tons of large stones, as a foreshore on the outer bank, beginning at low-water mark. Yet, in spite of all these precautions, in November, 1838, another gale smote the fabric, and in one night, as reported by Mr. Stuart to Admiral Warren, 9,000 tons of stones were washed out of their beds and hurried up the slope, many of them to a distance of 50 and 60 yards,

and even from below low water, and pitched over into the deep on the inner side. More buoyant objects performed still more extraordinary feats. A brig of 200 tons was carried clear over the works, and found herself swimming in the Sound inside the breakwater. It is just to add, that Mr. Stuart attributed much of the disturbance which the work had undergone, to the exclusive use of very large stones, on the bad effects of which Mr. Rendel gave evidence.

Mr. Stuart, though fully sensible of the value of large masses, had, nevertheless, early convinced himself, that a due admixture of all sizes was advisable, and in 1816 his representations to that effect, were sanctioned by the authority of the late Mr. Rennie, and by the permission of the late Admiral Sir Joseph Yorke. Still, although this course has been acted upon for thirty years, perfect stability has apparently not been insured. The original estimate contemplated 2,000,000 tons of stone, and an outlay of £1,161,000. The actual quantity of stone deposited, has been 3,514,885 tons, and when the work is completed, which Mr. Stuart expects will take place in 1849, the expense will be within £1,500,000. Here is an excess over the estimate of about 40 per cent., notwithstanding the very favourable vicinity of the quarries to the work, it being a voyage of only four, or five miles from Oreston, which is a much less expensive affair, than one a hundred-and-forty miles from Portland. From the Channel Islands to Dover is still further. Yet the choice lies chiefly between those two places, unless the Engineer should be content to use chalk, concrete, or Kentish rag. Were such contingencies as happened at Plymouth, Cherbourg, Ardglass, Portrush, Kingstown, or Donaghadee to occur, as it may be contended they must, if the slope had been decreed for Dover, they would cause a fearful excess over the £2,500,000. One such night as that of November, 1838, would require ninety voyages of a vessel of 100 tons, with a crew of five, or six men, and a flotilla of half a dozen billy-boys, each of that tonnage, would be a whole year constantly employed, in bringing materials for the repair of that single night's havoc. The cost, at Plymouth, of embarking and discharging one ton of stone, was 2*s*. 10*d*., which would be at least trebled if it were brought from Portland.

In fact, the permanency of a long slope, would appear to depend on its being constantly and adequately supplied with a succession of materials: the shingle coming from the westward might aid in the first instance, by settling itself into the interstices; but no dependence could be placed upon it for any resistance, or for anything except as an ally and auxiliary to the masses. Nature is constantly washing away our coasts, even where she has provided them with

far more compact means of resistance, than loose masses of rubble. From the Land's End eastward, the work of destruction is progressing slowly but surely. The Scilly Islands were probably once a continuous part of Cornwall. "This tract of country, which," says Mr. Lyell, "if the tradition to that effect be true, was probably thirty miles long by ten miles wide, has been dispersed by the waves, and converted into shingle, silt, or sand."

St. Michael's Mount, now an insulated rock, was stated to have been formerly in a wood, several miles from the sea. These compact hard materials have been wasted and carried away, and yet able authorities still maintain, in spite of this demonstration from the effects of time, and the convincing failure of their own attempts, that the rubble principle may be successfully persevered in.

The only member of the Commission who appears to have adopted this opinion in its fullest extent, is Lieut.-General Sir Howard Douglas, who, besides his elaborate protest * against the resolutions of his colleagues, which the House of Commons ordered to be printed, presses most of the witnesses on the point, and thus gives rise to a very interesting discussion, eliciting many curious views.

Captain (now Sir William) Denison, R.E., having been directed to confer with Lieut.-Colonel H. D. Jones, R.E., on the best form and materials for the construction of a breakwater, reported in favour of a vertical erection of concrete blocks, each of 25 tons, or 30 tons. These he would manufacture at Dungeness, from the shingle there, and float them by camels, which, by weighing two hours before the top of the flood, he thought might arrive at Dover soon after high water, and deposit their load. With three stations, each of which would manufacture sixteen hundred blocks a year, of 20 tons, or 30 tons respectively, he would embark six at each station, on every day out of two hundred and seventy in the year, during which he thought the passage and freight were practicable. Sir Howard Douglas, in the course of his examination, asks him whether he is not aware, "that the resistance of the plane to the fluid, in the direction of motion, diminishes in a very high ratio, as the plane becomes oblique to the direction of the motion, in short as the cube of the sine of the angle of obliquity?"—"I am quite aware," replies Captain Denison, "that the resistance offered by, or to, a wedge-shaped body, is less than that opposed by, or to, a flat surface, and that it varies as some function of the sine of the angle of

* *Vide* Papers relating to the Harbour of Refuge Commission of 1846, on the several modes of construction referred to the Commission for their opinion. Pp. 3–51, London. 1847.

the wedge; but that does not apply in the present case: it applies to bodies moving through the water, or to bodies against which a stream of water is impelled. When a breakwater is the subject, the difference between the wedge-shaped form, or long slope, will be this: in the former case the wave would be compelled to break, and the whole weight of the mass of water, multiplied by the velocity with which it was moving, would be the measure of the force exerted on the slope; in the latter case, the wave, being merely an undulation, would rise up against the vertical face, and act by its statical pressure only." Sir H. Douglas hereupon asks, "Whether he intends to deny, that waves progress with a certain velocity?" "The wave," replies Captain Denison, "is moving with a certain velocity, but the water is not. If you look at the sea in a gale, the wave lifts the ship up and passes on, it does not carry the ship with it. There is a small drifting to leeward, caused by the action of the wind on the hull and spars." Sir Howard Douglas further inquires, "Is not the very force with which a wave is impelled up a slope, a result of the force which would otherwise exert a direct impulse on an upright wall and overthrow it?" Captain Denison answers that, "in case an upright wall was built in the centre of a slope, a wave breaking on the lower part of such a slope, would rush up it with all the force due to the mass of water, and to the velocity with which it rushes up the slope against the vertical wall; but when the wall is brought up, in deep water, from the bottom, the wave does not break at all, it is a mere undulation. If you try to drive a boat in and let it lie against a wharf wall, you will find great difficulty in keeping it there, the boat will fall away from the wall. You are certain, if you drift in a boat against the slope of the breakwater at Plymouth, that the boat will be smashed to pieces, and there will not be a shiver remaining." Again Captain Denison, observes, that "in the case of a dam across a river, the sloping form is used, not because it is the best form to resist impulse, but because by giving a wider base, there is a greater mass of matter to resist statical pressure."

Mr. Hartley, who has executed great hydraulic works at Liverpool, is examined by Sir Howard Douglas as to the action of the sea on an upright wall; Mr. Hartley admits, that "seas rolling in with on-shore winds, come in more and more precipitous in their face, and at length break; that in that state, they have an onward progressive motion, and consequently a percussive effect, which they cannot have against a dead body in deep water. The movement of the wave, *i.e.*, the hydraulic action, is, when it comes in contact with an inert body, transformed into hydrostatic pressure." Sir

Howard Douglas asks him, "How this can be?" and is told in reply, "As you come upon a flat shore, the resistance is less, and the impetus greater, which is not the case in deep water." Sir Howard Douglas repeats the theorem * he had before propounded to Captain Denison, and asks, "Where and in what depth does the wave break?" Mr. Hartley answers, that "it breaks, because it has nothing to resist it; it is the higher part of the wave which tumbles down, having nothing to sustain it." Another cause for its breaking, is the rake, or backward action of the surge. When a heavy gale of wind urges the sea violently against a lee shore, the upper portion of the water is acted upon more forcibly than the lower; it is clear, that unless there was a power in the sea, to recover its own level, by means of a rake, or under current, following the delivery of each breaker, the mass of waters would be heaped up many feet, or even yards, above their usual limits.†

Capt. Vetch is strongly in favour of the upright wall. The percussive force of the sea, as at Plymouth, is, he contends, created by the form of the breakwater. He states that "in going out of the harbour of Scarnish, in the island of Tiree, in a vessel of 25 tons burthen, she was carried three times up and down a rock, inclined to the horizon, at an angle of 60°, with the wind blowing fresh on-shore, without touching it, though her gunwale was within a yard of it." His opinion also is, that though "breaking waves would have, of course, percussive force against an upright wall, yet such a structure would receive no blow from an oscillating wave. By an upright wall, the oscillating wave is met before it is subject to be changed into a wave of translation."

Professor Airy is subjected to a similar examination from Sir Howard Douglas. In the shallow parts of the bay, where, without uncovering, the depth is such as to cause the wave to break, he would admit a slope; but in other parts, where the breaking of the waves can be avoided, he would have a perpendicular wall, on which, he says, there will be a great swell up and down, but it will not strike it; there will be nothing like horizontal motion. "I have

* An ordinary projectile, a pebble, or cannon shot, striking on an oblique face, doubtless, does less injury than when impinging at right angles; and so, also, waves, which may in fact ultimately be resolved, into an infinity of small globules. If they were projected with the same force against both upright walls, and long slopes, (which they are not,) and were the masonry of the long slopes equal to that of the upright wall, (which it never is,) Sir Howard Douglas' proposition might then be applicable.

† They certainly do raise the level of the water in-shore, as is observed by Mr. Scott Russell in the page already quoted.

been in circumstances," continues Professor Airy, "where I have had great opportunities of observing that practically, and I know that such is the case." He further states, that on one occasion, when rowing out of the harbour of Swansea, his boat was carried close up against one of the pier heads, in a heavy sea, which washed two of the rowers overboard, but that the boat was not dashed against the pier, as he contends must have been the case, if it had been one of the structures with a slope of four to one.

"The effect of a sea," (observes Professor Airy, in a series of remarks, forwarded to the Commissioners, in November, 1845), "even when it breaks on masonry, is (56) probably not to dislodge it by pressure on the surface (57); but in the first instance to remove particles of the cement, small stones, &c. (58); next, when the crevices are entirely filled with water, to cause by its impact a heavy pressure, like the blow of a hammer, upon the water in the front crevices, which, as in Bramah's press, or in a hydraulic ram, is then communicated to all the water in the crevices, and acts on all the back surfaces in the masonry (59)." Thus he considers, that facing stones are usually forced out front-ways (60), and it is "probable, that a sea breaking somewhat obliquely is more dangerous than one which breaks quite in front;" (61) because the back pressure is exerted behind individual stones, by the action of the first crevice which the sea strikes upon, before there is an opposing front pressure.

Professor Airy disposes (65) of the argument in favour of the long slopes, drawn from the form which nature gives to beaches (67), "because, in general, though the form of the whole is preserved, the individual materials are in a constant state of change and ruin, and are, by the action of nature in other parts, continually replaced by new materials." (69) Then a long slope causes the sea to break very heavily; and (70) remarking, that the proposed slopes are like those of the Chesil Bank, where the surf is the most tremendous that he has ever seen, he imagines, that the surf on such a slope as the Plymouth Breakwater must be exceedingly heavy. Nothing can be more exact, minute, and methodical than Professor Airy's inductions, step by step, relating to the separate difficulties of shingle, of silt, and of construction, in his evidence and conclusions relative to Dover Harbour. To his authority must be added that of Mr. Brunel, who favours the upright wall; Lieut.-General Sir J. Burgoyne the same, as well as Mr. Rendel, Colonel Jones, and Captain Denison. Sir John and Mr. Rennie, and Mr. Cubitt sent in, respectively, the sloping projects, though the latter, in 1844, was an advocate for an upright wall in caissons; Mr. Vignoles

advised a slope up to low-water mark, and an upright structure above.

Having so far treated of the profile, or section, the execution remains to be considered. Sir W. Denison suggested the manufacture of concrete blocks, at Dungeness; Mr. Walker proposed building portions of upright walls in caissons, at Portland, floating them thence to Dover, and then sinking them. Mr. Rendel would unite bricks by cement, or by vitrification, into masses of 8 tons each, at Dover, or as near as they could be procured, and build them into an upright wall by means of divers. The outer surface of these masses would consist of hard blue bricks. The Commissioners gave the preference to Mr. Rendel's project and mode of construction, subject to some modification of the east and west entrances.

It has been already stated, that Sir William Symonds was the sole dissentient, from the proposition to make a harbour of refuge at Dover. "The mass of evidence," says he (7th August, 1844), "is in favour of Dungeness; the holding-ground at Dover is indifferent, and the Engineers say it will silt up." With regard to the last of these objections, it will be recollected, that Captain Washington's Reports, in reference to this point, and his calculations indicating the utmost probable quantity to be contended with, are of the dates respectively of March and November, 1845, posterior to Sir Wm. Symond's protest of 1844, and it must be observed, that they certainly are calculated to allay his apprehensions, with regard to the holding quality of the bottom of the bay. The 'Blazer' was ordered to proceed there and to test the question. She did so, embarking the Harbour-master, and Captain R. Manners, R.N. Eight trials were made; in none was the ship going at less than three knots over the ground, so as to represent a vessel bringing up (p. 33) in a crowded harbour; and in conclusion, Captain Washington says, the tough nature of the ground was far better than, from common report, he had anticipated, and that from the trials he had made, he should, even in its present state, have no hesitation in riding out a gale of wind in the bay. In this Report the officers and the authorities he had with him, entirely concurred.

Sir Howard Douglas, in return, gives his reasons for disagreeing with the recommendations of his colleagues. He complains, that the number of openings have been reduced from three to two; that the omission of a western entrance, will render ingress and egress less easy, and that the lack of a tidal current will promote the tendency to silt up. The ingress and egress, however, can hardly be

inconvenienced from that cause, when it is recollected, that there may be steam-tugs for the latter, and possibly, even to facilitate the access of any vessel labouring to obtain admission, but being unable to fetch in; while the fewer the openings the more quiet the harbour will be found, when once it is entered.

Several authorities are then given who are opposed to upright walls; some upon the theory that they are unable to resist the force of the waves; others from the practical difficulties in the way of their construction, at 40 feet below the water.

In Sir Henry De la Bèche's, "How to observe Geology," concerning the action of the sea on coasts, occurs the following passage:—"If a mass of fallen rock be stratified, much will depend on the face presented to the breakers, for if it fall so that the plane of the bed remains sloping seaward, it will act as a well-contrived wall, erected to defend the cliffs; but if the bed should remain vertically exposed after the fall, the future destruction of the mass would be far more rapid."

Now this does not sanction Sir Howard Douglas' argument; because a mass of rock may have been precipitated down, without any bed having been prepared for its reception, to take its chance among the other loose materials already there below, and for the most part inclining to slide outwards, and that mass happens to lodge in a vertical position, it is assumed, naturally enough, by Sir Henry De la Bèche, that such a mass is more likely to be undermined and be again dislodged and transported, than if it had sloped backwards. There is no doubt, that without foundation, cement, or masonry to aid and retain it, it would yield as soon as its equilibrium was again disturbed; but this only proves, that a breakwater of loose stones, dropped in one by one, is not likely to stand at any angle approaching the perpendicular, which indeed was not contended for.

Loose materials, which become accidentally exposed to the action of the sea, in an upright position, cannot fairly be compared with perpendicular masonry erected for the purpose, with peculiar skill and care.

Nor is Sir H. Douglas entirely successful, in another part of his inference from the same work, when he speaks of the force exerted against a rocky coast. The Author, speaking of a heavy Atlantic swell striking the coast, says:—"The blow is sometimes so heavy, that the rocks will seem to tremble beneath his feet; he will generally find in such situations, that though the rocks are scooped and caverned into a thousand romantic shapes, they are still hard rocks, for no other could continue long to resist the almost incessant action

of such an abrading force." Now this scooping and caverning fully explains the trembling under foot. For though the general elevation of the coast be perpendicular, yet the occurrence of chinks, fissures, and cavities of various forms and dimensions, present as many hydraulic presses, in some instances, and water-rams in others, whose effect will sufficiently account for the disintegration of the masses, so that though generally upright, the conditions are essentially different from the smooth face of masonry, which, at whatever angle with the horizon, would present no such opportunities to the grasp of the enemy.

Then as to Cherbourg, Sir Howard Douglas thinks this may serve to demonstrate the superiority of the principle of the slope, and he relies much on the fact of the United States Government, having determined to adopt that method, for the breakwater they are about to construct in Delaware Bay. But after carefully perusing the documents issued to their countrymen, by the three American officers, it must be owned, that the reasoning appears inconclusive, and its framers take no notice of the disasters that have befallen the great French work since the Peace. Besides, there the principle has actually been abandoned, with regard to the after-portion of the work, and a vertical wall has been erected on the rubble. Outside this again is a foreshore of loose stones, intended to catch and break the waves, and to keep them from assaulting the wall, with all their accumulated strength. Professor Airy, in adverting to this mode of construction, which had been proposed in one or two of the plans laid before the Commission, pronounced it to be the worst. A slight examination shows, that the eminent French Engineer who resorted to it was not his own master; he made a merit of necessity, doing the best he could, under existing circumstances, to obviate the consequences of having adopted an erroneous principle in the beginning, and which, after forty, or fifty years' perseverance in it, had been found inadequate, and had been abandoned.* But the dilemma was in the fact, that although the

* Mr. Stuart, of the Plymouth Breakwater, confirms Mr. Airy's theory by his own experience; he objects to the solid body in the middle, (as at Cherbourg,) since "the rough stones would then blow out." "Why do you object to that?" asks Sir Byam Martin.—"Because the solid body in the centre would resist the air and the sea, and blow up what is outside; we know that from experience." "How do you know that from experience?" inquires Sir Byam.—"By building up solid masonry every year at the end of the pier, at the west end; when a storm comes, the solid masonry causes some of the stones to be thrown out; the action of the sea blew up a few of the stones." *Question.*—"The solid masonry is on the top of the rubble, whereas the pro-

deposited materials were neither trustworthy, nor secure, it would have entailed an expense, almost equal to the original cost, to have removed them down to the bottom, in order to obtain a proper foundation. To sling, hoist up, and transfer elsewhere the stones of which it was composed; to excavate, at 18 feet below low water, a rectangular trench of at least twice that width, and nearly three miles in length, was hopeless. The placing then of the vertical wall on its rubble substructure was unavoidable. The foreshore was intended as a shield, and it must be owned, that the large masses arranged along the foot, supply the raging elements with a most destructive artillery.

In the protest is contained an abstract of some opinions, delivered at the Institution of Civil Engineers, in April 1842, in a discussion on Colonel H. D. Jones' Paper on Breakwaters.* It is argued, that "if the materials are deposited at an inclination, any portion being displaced is only carried down elsewhere." It would be well if this were so; but it is not the fact. They go down elsewhere certainly at last, but in the wrong place; in the harbour's mouth, as at Ardglass, or Donaghadee, or inside, as at Plymouth; and it is only after a most destructive and grinding course, that they finally close their stormy career under the ceaseless billow.

Sir Howard Douglas, from the frequent reference which he makes, both in his examination of the witnesses, and in the tenor of his argument, appears to have adopted some of the theories of Colonel Emy, an eminent French Engineer.

When the masonry dyke at St. Jean de Luz, was destroyed by the sea, Colonel Emy substituted for it a long slope in sand, at about eleven to one, which, when he wrote, (in 1831,) had stood well. This may answer for the bight of the Bay of Biscay, where, though there is a rise, there is not a strong tidal current. It will not do at Dover, with the Brake Sand moving bodily one-third of a mile from its former place in forty years; with a whole mile of one bank, and half a mile of another washed away at Dungeness; and all this due to the ebb and flow alone, for neither of these banks are ever uncovered. All hopes of building solid structures on the sand, with such agencies around, must be given up. Besides, Colonel Emy appears to have considered his operations only as a temporary substitute for more solid masonry, for he complacently says, "it answers the object, which was to place the town out of

---

position you are now alluding to, is the solid masonry below and the rubble above?" *Answer.*—"So much the worse."

* *Vide* Minutes of Proceedings Inst. C.E., 1842, vol. ii. pp. 124–131.

danger from a fresh assault of the sea, and to give time to the Engineer to devise masonry, which will certainly be more expensive to execute, but which will, perhaps, not be more efficacious, or so easily maintained in order." His work contains a very graphic representation of the great storm at that place in 1822, which tore up the loose rocks of 2 tons weight, though confined by a stockade of piles at the foot of the scarp, or sea wall, using them to batter and destroy the glacis above, and which, by the bye, was something similar to that at Ostend, so much commended by Mr. Rennie; an earthen mound, closely packed with large stones, presenting a smooth face, like the present shore adjoining the Cheeseman's Head at Dover.

Colonel Emy's book, "Du Mouvement des Ondes," came out in 1831, when the resolution to found the solid wall upon the rubble pile at Cherbourg, had been adopted, but not executed. In commenting upon it, he foretold with rare exactness and sagacity, its probable fate. Emy anticipated this from his nostrum, the "flot du fond;" but from whatever cause, the result has manifested itself. The large stones used in the foreshore, he predicted would be used by the sea to batter the defences, and be liable also in gales, which swept obliquely to the face of the work, to be rolled along to either end, and be flung inconveniently athwart the entrances, as occurred in the Irish harbours previously mentioned.

Colonel Emy, however, is not to be reckoned among the advocates of the long slopes of rubble. He distrusts the vertical wall, the merits of which are, of course, much influenced by the size of the stones used, and which, judging from the illustrations, seem to have been less than half a ton weight, and he recommends a curve, or arc of stone 60° of a circle, whose radius may be 25 feet, or 30 feet, with the indispensable condition, that to this curve the bottom of the sea and the upright facing at the top, should respectively form tangents; the latter at such a height, that the "flot du fond" may not reach it. The stones of which such a work is composed, are to be very hard; because if the shingle is dashed against the face, as he has found in a revêtement at the Isle de Rhé, built under his superintendence, it is apt to be ploughed into by the action of the pebbles.

Another curious fact is mentioned, which it is as well to bear in mind, since it is probable that a hearting either of rubble masonry, chalk, or concrete, will be adopted for filling in the work at Dover. He found by the uneven settlement of the two materials, that is, of the incompressible freestone used in the front of his work, and of the rubble of which the backing was composed, the solidity of

the fabric was impaired; for the latter, in sinking, carried down with it the tails, or inner extremities of the heading stones, whose outer ends being thus canted up, let go the stretchers, which were then displaced. Concrete once consolidated has no tendency to settle; but then it is generally used in places where it can be wheeled to a stage, and be shot into its bed from a height, the impetus of its fall serving to consolidate it at once, and give it a firmness, which the more regularly laid rubble, can only derive from the slowly-increasing weight of the masonry as it rises. In the sea, however, nothing of this kind can be done; the material itself loses weight, and bodies with which it might be attempted to pound and consolidate it, become inefficient and unmanageable by immersion.

Emy's theory of the "flot du fond" appears to have struck Sir H. Douglas, and some of the Engineers. That writer has attributed to it most extraordinary effects, well calculated to strike the imagination of his readers. It is this submarine phenomenon, according to him, which has caused the ruin of so many hydraulic works and even of cities, which has changed sea into land, and *vice versâ*, and which has filled up ports with sands, and formed land around towns, whose walls were formerly bathed by the ocean. All these, continues he, have been wrongly attributed to tidal currents and the simple action of the surface waves, "mais le phénomène des flots du fond va reprendre ses droits, comme formidable agent de la puissance des mers sur le globe."

In France, men and things seem to be always floating between restorations, legitimacies, and usurpations. Brémontier and La Coudraye may have been considered by Emy to belong to this last class. Brémontier's notion was, that all undulation was vertical, so that if a staff was so weighted as to be a suspended plumb in an agitated sea, it would maintain itself there, and a wall thus erected would, in consequence, have no great effort to sustain. He accounted for the great swells not accompanied by wind at the place of their occurrence, by the hypothesis, that they had been propagated in distant quarters, and on arriving in soundings and not finding there sufficient depth, were deflected upwards from below. La Coudraye, in accordance with the opinions of French naval men, reasoned, that their occurrence denoted a change in the depth of the sea. Emy objects to both these definitions, and insists, that a rapid rise, or an abrupt shelf, occurring at the bottom, is necessary to produce this "flot du fond," which he assumes to be the effect communicated to the vast oceanic mass, by a gale blowing with sufficient force and duration, but perhaps in some distant quarter.

He thinks, that as long as the bottom is tolerably even, the uniform action of the "flot du fond" obeys the impulse derived from its original cause; but on finding a commensurate obstacle rising across its course, such as a reef, or sudden shoaling, it is then diverted upwards with force enough to intercept and modify, and sometimes even to arrest the further progress of the waves on the surface; but to produce this last effect, the volume of water above, or rather its depth, must not be very great. The "flot du fond" arriving at the foot of steep cliffs will explain, in Emy's view, the extraordinary height to which volumes of water are sometimes projected up their sides, (as against the Edystone Lighthouse, or at Warberg in Norway,) and he fancies they can be distinguished from the other waves in the rollers that break upon a sloping beach; but Emy would derive, indeed, almost everything from the "flot du fond."

However ingenious this theory is, it is at least as experimental as that of the vertical wall. Mr. Rennie, in answer to a question from Sir H. Douglas, is inclined (435) to allow considerable action to the "flot du fond," that it has very great power to move shingle and small stones, and that (438) in their advance, a sloping shore makes them jump up and remove obstacles.

In the Mediterranean he does not think a "flot du fond" exists (471), though he is aware, as stated by M. Poirel, that masses of 8 tons weight have been moved by the sea, several hundred feet at Algiers, in a depth of water of 28 feet.

Mr. Airy, in his Essay on Tides and Waves, doubted whether any of the theories of Emy, Brémontier, or La Coudraye, could be maintained, while Mr. Scott Russell's experiments and researche have led to other conclusions than Mr. Airy's.

It is to be regretted, that the Commission did not obtain the opinion and assistance of Mr. Scott Russell, whose views have been slightly alluded to by Sir Howard Douglas, as favourable to a breakwater with a parabolic section; such a curve agreeing with what he shows to be the profile of the wave.

Of course the cost is greater from the enlarged sectional area; the workmanship of the voussoirs would require more time, and the nearer the curve, whether parabolic, or segmental, tended to coincide with a tangent at the bottom, the more caution must be used in excavating a proper bed for the abutment of the reversed arch, which would otherwise buckle, or squeeze outwards at its base.

Mr. Alan Stevenson has been much relied on by the opponents of the vertical principle. In order to test the force of the waves, Mr. Stevenson had constructed a marine dynamometer, in which a

flat disc was so disposed as to receive the impact of the sea, while the force of the blow was measured, by the compression it exerted upon a spiral spring, the area of the one, and the power requisite to strain the other, being previously noted, and their relations to each other ascertained. The instrument was fixed to a rock between high and low water, and in situations exposed to heavy seas. It was of course impossible to obtain the effect of any particular wave, but the instrument was so contrived as to register the greatest shock received from any one wave. In the most exposed situation, and in the most violent gale at Skerryvore, open to the Atlantic, the greatest force registered was equal to a pressure of 6,000 lbs. per square foot; a formidable power certainly, and which, he contends, no mere vertical erection could resist. Mr. Stevenson does not appear to draw any distinction between the force exerted by a sea in its breaking state, (such as the instrument was exposed to,) and that belonging to the unbroken wave. What he states respecting the height to which the water is projected upwards at Barrahead, Fishguard, and the Pentland Skerries, is an exemplification of the abstract description of Sir Henry De la Bèche. The same consideration will explain another circumstance, which he regarded as conclusive, viz., that vessels are often pooped at sea. Undoubtedly, when a vessel sails at the rate of ten miles, or twelve miles an hour before a heavy gale, she must be overtaken by waves moving at a greater velocity. If, at such a moment, any unconformable movement, heel, or lurch of the ship, forces the sea to gather under her projecting counter, the cavity will, by violently disordering the wave, compel it to break and roll over her poop. In some situations, more depends on the exterior profile of a wave than in its rapidity, or even its height. During the fortnight Mr. W. Walker observed their movement at Bovisand, their height above the mean level was, one day, 27 feet, and their velocity thirty miles an hour; and, a few days after, with a height of only 5 feet, the velocity was thirty-one miles an hour. This railway speed is a mere snail's pace compared with that of the great primary wave which, heaving under the flag-ship of the Commander-in-Chief, at the Cape, at noon, washes past the Azores at midnight, and after rounding the north-east of Scotland, floats the colliers at Dundee by the middle of next day, within twenty-four hours after receiving its first impulse in Simon's Bay. This wave, in some parts 4,000 miles long, moves in the deep sea with a speed of three hundred and fifty to four hundred miles an hour; ten times that of the furious waves observed at Bovisand, and yet, excepting in those peculiar situations where the bore, or 'mascaret' is produced, this tidal wave never breaks.

If Mr. Stevenson is right, what ought to be the effect of a wave against the Edystone? for, in that structure, there is a profile up which the sea is known to be projected, with a surprising display of power. The outline approaches so nearly to the vertical, there being but 4 feet batter in a height of 35 feet, that it may be practically treated as a perpendicular structure, and be considered as open to the Atlantic storms as the Skerryvore.

Without subscribing to the full extent of the force supposed to be exerted by the ocean, it may certainly be admitted, as a demonstration of the inherent facility, possessed by the sea for removing loose stones of 15 tons, or 20 tons, as it is known to do. Whatever be its force per square foot, the wave is at least able to concentrate the whole of it on the comparatively small surface presented to it, and to deliver it at a single blow. But, in the case of a solid piece of masonry, the conditions are altogether different. If waves of 300 yards, or 400 yards long, and 8 yards, or 9 yards in height, such as have been observed by Mr. W. Walker at Bovisand, were to strike an erection at one and the same moment, with the accumulated force attributed to them, the result might be its destruction; but this never happens. Where such waves approach the shore directly, their centres becoming higher, tumble over first in the middle, while their flanks, right and left, are only rising to a crest. When the wind blows obliquely towards the land, the waves come on accordingly, bringing up first the leeward extremity, which is broken and disposed of, before the windward one is delivered. Besides, observation and theory tend to establish the fact, that against an upright face, waves have no motion of translation and do not break. Moreover, the height to which volumes of water are occasionally projected upwards, of which such extraordinary examples can be found, is not at all in comparison with, or a measure of their effective assault upon the coast. It may be a resultant, or an indication of a force possessed by a wave, but which has not been so directed as to produce destruction of the cliff, or structure, which it scales. A horse closely hobbled, or fettered, may make violent exertions to escape, the amount of which, could he break away and begin his course, would carry him over a turnpike gate, or through a square of infantry; but he is checked long before he can acquire his momentum. A man, with his arms pinioned, vainly exerts animal power in endeavouring to strike a blow, which would fell his adversary, could he but muster an impetus to deliver it, in the right direction. An arrow may be retained in the bent bow, already drawn for its emission, with a far less force than that which would be required to resist its flight through the air after its discharge.

These are instances, which may serve to illustrate what appears to be the difference, between the wave which is permitted to break upon a slope, and that which is restrained by a wall, up which latter the vertical column of ascent may run to great heights, and yet be, comparatively and literally, a harmless firing in the air.

In conclusion, it may be observed, that although for a point, like Dover, in advance of our own shores, whereon to mount guard over the Channel, pregnant as it is with dramatic and historic interest, we may resign ourselves to incur much cost to prepare it for all that is expected of it, we cannot afford to have many Dovers. Time, too, is something. Cherbourg Breakwater took two generations of men to bring it even to its present state. Plymouth has already occupied more than one generation. And when the Astronomer Royal, familiar with studies of the heavenly bodies, in which "a thousand years are but as one day," tells us, that "the question of duration is between fifty and five hundred years," we feel a melancholy confirmation of the sentiment of the poet:*—

> Debemur morti nos nostraque ; sive receptus
> Terrâ Neptunus classes aquilonibus arcet,
> Regis opus ;——

nay, remembering Captain Vetch's projected estate of eight thousand acres on the Goodwin Sands, the rest of the passage is equally apt:—

> —— sterilisve diu palus aptaque remis,
> Vicinas urbes alit et grave sentit aratrum.

Mr. WALKER said, the Institution and the profession generally, must feel deeply indebted to Lord Lovelace, for this excellent and practical essay, on a subject demanding all the careful investigation and patient research which had evidently been bestowed upon it; and he must say, that the opinions given upon the Reports published by the Government Commissioners, whence the information had been almost entirely derided, would have done honour to any Civil Engineer of long experience. It was not the custom in this country to confer titles upon Engineers, but the Institution had now seen a Peer become, for the time, an Engineer, and in that capacity arriving at conclusions on engineering points which displayed great critical acumen and sound judgment. It was to be regretted, that circumstances would not permit a longer time to be devoted to the discussion of the Paper, as the subject was of great interest, not only to the profession, but to the nation at large.

* *Vide* Horatium de Arte Poeticâ.

Before proceeding to the discussion of the purely engineering portion of the question, there was one point which should be understood, but which had not, Mr. Walker believed, been mentioned in any of the Reports. He alluded to the indifference, almost amounting to a positive objection, on the part of the mercantile shipowners, to the formation of harbours of refuge. In fact, except for avoiding the loss of human life, it was of little importance to them to diminish the present risk, or whether a ship ever arrived at its destination at all. A vessel, when freighted and on her voyage, was generally fully insured; the profit depended upon the speed with which she made the passage, and the number of cargoes she could carry in the year. She must run some risk, and carry on in all weathers, so as to arrive quickly. But the shipowners argued, that if the harbours of refuge afforded shelter, the captains would run for them under the slightest stress of weather, and that their time would be wasted; in fact, as they expressed it, "that the breakwaters and harbours of refuge would be positive nuisances," which "lazy and timid captains would convert into skulking-places."

The intention of Lord Lovelace's Paper was evidently to make a summary of the arguments for and against the various sites proposed for the harbours of refuge, and the several kinds of constructions contemplated; criticising at the same time, the structures that had been raised in numerous situations on the coasts of Great Britain and Ireland. Mr. Walker would allude to two of the principal works, Plymouth and Dover, as they had been more particularly under his own direction.

The breakwater at Plymouth had been under his charge for the last ten years, and he must contend, that it could not now be considered an unstable work, although, until the materials found their own slope, it might have been expected to yield to the furious attacks of the sea, to which it was subjected.

It was a matter of history, that the original design for the Plymouth Breakwater was somewhat similar to that for Cherbourg; a long slope below low water, upon which a nearly upright wall was to be placed. In the course of the construction of the first portions of the work, after a slope above low water was adopted, Mr. Rennie and Mr. Whidby perceived, that the slope must be changed, from three to one, to five to one, and they immediately adopted the latter inclination, because they saw that the sea placed the materials at that angle. The body of the work was now so firmly consolidated, that since the last great storm, mentioned in the Paper, but little injury had been received, except at one spot, where the foreshore and the facing had suffered to some extent, in consequence of the rubble-

stone composing the former not having been carried out to the full extent.

At the west end, Mr. Walker had advised the construction of a buttress, formed of large blocks of cut stone, built in steps, having their rise equal to the tread, and thus bringing the body to an angle of 45°. It was executed with peculiar care, with a vertical bond throughout, each course being tied by a dovetailed stone, into that upon which it rested. It was found, that the severest storms had never caused any disturbance of this portion of the breakwater; and he thought, if that system had been carried out more extensively, the whole structure might have required less repair than it had done.

He had carefully observed the action of the sea upon the breakwater, and he was of opinion, that the waves rose higher upon the buttress than over the long slope.

He agreed with the propriety of increasing the amount of small rubble-stone in the formation of maritime works, to fill up the interstices between the large stones, and thus to render the whole fabric as solid as possible; but he must state, that Mr. Stuart disagreed with Mr. Rendel, as to the amount of vacuity in the Plymouth Breakwater. The object of Mr. Walker's first visit to the Breakwater, in 1838, was to report upon the cause of the large squared stones being forced, or torn out of the surface of the upper part of the slope. He attributed it to the hydraulic pressure acting upon the under sides of the stones, when a partial vacuum was formed above them, by the passage of a wave over them. His observations of the tremendous effects of these united influences of the pressure beneath and the vacuum above, had induced him to recommend the system of filling up the vacuities with small stones, so as to render the whole body, as nearly as possible, a solid mass.

With respect to Dover, the difficulties mentioned by the authorities quoted by Lord Lovelace, did apparently exist, and perhaps it was right to examine into them; but Mr. Walker would show, that they were more apparent than real.

As to the shingle, it was true, that formerly such quantities were frequently brought into the mouth of Dover Harbour, by a gale of wind, as to render it impassable for vessels, during several tides. But the South-Eastern Railway Company, by throwing down immense masses of chalk rock and building groynes, had either stopped the progress of the shingle, or had so completely diverted it into another direction, that the Commissioners considered the bar at Dover no longer to be dreaded, and the complaint now was, that there was not enough shingle to keep up the shore and the buildings. It was

true, that in course of time, the shingle might get round these projections; but as the present contract, entered into by the Admiralty, was for the construction of a pier 800 feet in length, he thought, that ages might elapse, before such an accumulation of shingle could occur, as would fill up the space between the shore and the pier; and he believed, that the current having once received a direction outwards, would be prevented from again turning in-shore. In fact, the Commissioners felt so well assured of the shingle being no longer a subject of alarm, that they had a Bill before Parliament for the extension and improvement of the harbour.

Then, as to the silt, Mr. Walker agreed, to a certain extent, with Captain Washington, that a portion was held in suspension, but only for a short distance from the shore. The appearance of discoloration arose, most probably, from the quantity of chalk débris which abounded along the shore; but it was so light, that he believed nearly all the silt brought in by the flood, was washed away by the ebb in heavy weather, and it would be found at Dover, as at Kingstown, that no detrimental deposit of silt would occur. This was the case at Plymouth, where the fears of deposit were proved to be groundless.

A great portion of the examination of the witnesses before the Commissioners, had turned upon the preference to be accorded to vertical walls, or to slopes. Now Mr. Walker submitted, that each would answer the purpose, and had its comparative advantages, and that a Civil Engineer should not adopt either form, as generally and indiscriminately applicable for all situations; but should use either, as his judgment of locality, and of the prices and quality of materials at the place dictated. In the decision, many points should be considered. Mr. Walker's general predilection was in favour of a long slope, because, from experience, he found, that it offered less direct opposition to the waves. For instance, the same sea which rolled harmlessly over the slope at the Plymouth Breakwater, would strike the buttress with great force, and rise to a considerable height.

The comparative expense of the two kinds of structure also required to be considered. At Dover, a slope would cost much more than a vertical wall, because of the deficiency of proper hard materials. The same stone, which at Portland would cost three, or four shillings per cube yard, could not be procured at Dover under three, or four times that amount. The Government had, therefore, resolved to face the Dover Pier with hard ashlar stone, and to build it nearly upright. In this position also, a long slope would not have been applicable, because vessels could not safely come alongside in rough weather, to load and unload their cargoes, or passengers.

At the Channel Islands the quality of the granite was generally acknowledged to be excellent, yet Mr. Walker's first step was to open quarries, in order to ascertain precisely the quality and price of the materials. He then recommended a long slope, with a wall sloping at an angle of one to one at the top, because the cost of a vertical wall would have been greater, on account of the more careful workmanship required for its construction, and the materials being ill suited for squared work.

Time would not permit him to multiply examples, of which there were plenty existing, to show that no Civil Engineer of eminence attached himself exclusively to one form of construction; but that he adapted his practice to the locality, applicability, cost, time of execution, and numerous other points, familiar to every one having the direction of large works.

Sir JOHN RENNIE begged, in the first place, in common with every Member of the Institution, to thank the Noble Lord for thus coming among the Engineers and taking part in their discussions, as well as for his Lordship's very interesting Paper upon Harbours of Refuge, in which the arguments for and against the contemplated sites and modes of construction, were so fairly considered. He was very sorry, therefore, to be unable to agree with the conclusions arrived at by his Lordship, from the documents to which he had access. To pass in review the whole of the subjects which had been treated of, would be foreign to his purpose, and might, he feared, be found rather tedious. Sir John would, therefore, confine his remarks chiefly to those parts of the Paper relating to the works in which his father and himself had been concerned, and upon which, he regretted to find, that the Noble Lord had not obtained more accurate information, but which Sir John Rennie would have had the greatest pleasure in supplying; and he felt convinced, that if such information had been communicated, his Lordship would not have made the remarks upon those works which were contained in the Paper.

As regarded Captain Vetch's plan for converting the Brake Sands into a breakwater, Sir John Rennie thought, that the idea was entertained by him about the same time, if not previously, and was explained in his Report to the Trustees of Ramsgate Harbour on the 15th of March, 1842.

As regarded Plymouth Breakwater; notwithstanding all that had been said against it, he was prepared to maintain, that whether as regarded the plan, or the mode of carrying it into effect, nothing could have been more successful. Originally, Plymouth Breakwater was only intended to have been raised to about the level of

half tide, because it was conceived, that sufficient protection would thereby have been given to the anchorage in the Sound, and it was not deemed advisable to incur greater expense, than was absolutely necessary, or to run any risk of injuring the harbour in other respects. Accordingly, the original quantity of rubble was calculated at 2,000,000 tons, exclusive of the subsidiary pier at Point, and the masonry at 1,353,500 cubic feet, at the estimated cost of £1,059,674, exclusive of the pier at Andurn Point; but, as the work proceeded, the original calculations were proved to be so well founded, that more protection could be given to the anchorage in the Sound, without interfering with the general convenience of the harbour in other respects; it was, therefore, determined to raise the breakwater from the level of half tide, according to the original plan, to the height of 2 feet above high water, of average spring tides. This departure from the original plan greatly increased the extent of the whole work, and induced corresponding alterations in the form and quantities of the materials. It also augmented the cost in the same degree; but, making due allowance for this, it would be found, that the breakwater would still cost £290,000 less than the original estimate. The mode of construction adopted, after mature consideration, was the rubble system, which consisted in employing only angular blocks of stone of different sizes, as raised from the quarries, and depositing them by their own gravity in the line of the intended breakwater, leaving the action of the sea to consolidate and dispose of them, according to such a form, or angle of repose, as might be best adapted to resist the waves during storms. Such being the principle of construction adopted, it followed as a necessary consequence, that the exterior form of the rubble mass would, from time to time, be subject to alterations, until the desired angle of repose had been obtained; in fact, the waves themselves, as so well expressed by the late Mr. Rennie, became the principal artificers, or masons, in working the deposited materials into a proper form; and a considerable portion of the workmanship, which otherwise must have been executed artificially, was effected by the waves themselves. All the changes of form which inevitably followed, during the execution of the work, far from being disasters, as they had been improperly termed, in the Report of the Refuge Harbour Commissioners, had been foreseen and calculated upon, in laying down the original plan and estimate. This had been repeatedly explained to the Admiralty, both by Mr. Rennie and Mr. Whidby, in their reports upon the progress of the works.

As regarded the changes of form; by referring to the various sections taken at the time, it would be seen, that the effects of what

had been termed failures, or disasters, were merely confined to the surface of the exterior, or sea slope, extending from a few feet below the level of low water of spring tides upwards, and the only result was, that the surplus rubble was transferred from the sea to the land side; thus rendering the angle of the sea slope rather more than five to one, and reducing the land slope to an inclination of two to one, and in that state the rubble generally remained quiescent. The rubble foreshore was added on the outside, at the recommendation of Messrs. Chapman, Jessop, G. Rennie, and Sir John Rennie, and the addition was approved of afterwards by Mr. Telford. In fact, it was a necessary consequence of raising the whole work from half tide to above high water of spring tides. The casing of masonry was at length added, for the purpose of preventing the occasional changes on the surface, before alluded to, and of giving a finished appearance to the whole work; although, as regarded the great object of the breakwater, in affording protection to the Sound, that had long been answered, and the additional cut-stone masonry was not essential.

With regard to the observation, that the rubble was not sufficiently solid, nearly the same answer might be given; that the alterations of form had been almost entirely superficial, and were confined to the exterior slope; that the main mass, or body of the work, had not been disturbed, and that no blocks had been removed from the line of the work, as was proved by sweeping the Sound with a diving-bell, in order to set at rest the doubts and observations of those who entertained a contrary opinion; so that no object but increased expense would have been obtained, in rendering the main mass more solid. Again, quantities of smaller materials, as well as certain portions of quarry rubbish, which were sufficiently hard, were used, according to the original specifications of the late Mr. Rennie, and of Sir John Rennie, where they were necessary, both in laying the masonry for the foundation of the lighthouse, as well as in preparing that for the masonry casing, on other parts of the work. The rubble which it was necessary to remove, in order to prepare for the masonry, was subsequently found to be so solid, that it could only be worked out as from a quarry.

As regarded the occasional displacement of portions of the masonry casing; that must be expected in all large works, and the fact of its having occurred formed no real objection to the system adopted, and whenever, by duration of time, the subjacent rubble had become consolidated, and the foreshore was properly kept up, and the cut-stone masonry well laid, it had been found to stand well.

In several places Sir John Rennie had tried vent-holes, for allowing the air to escape from beneath the masonry casing; but when the rubble was sufficiently solid, they were unnecessary.

If the plan, now advocated by the Commissioners, of constructing a solid vertical wall from the bottom of the sea had been adopted, the almost endless time and cost would have rendered it, to a certain extent, impracticable; but even supposing, that it had been attempted, the expense of the repairs would have been far greater than that of the system adopted. Indeed, the almost vertical wall of solid masonry, built upon the top of the rubble-work, which had failed, was constructed by Mr. Whidby, against Sir John Rennie's advice. It was also disapproved of by the late Mr. Telford, Mr. Chapman, Mr. Jessop, and Mr. G. Rennie.

By the plan adopted, considerable protection was afforded to the Sound, within eighteen months after the commencement of the work, and within twelve years the whole anchorage was rendered safe, which, considering the mass of work, executed in such an exposed situation, was certainly a very small period of time, and could not have been effected by any other plan. By making allowance for the additional quantity of workmanship and materials necessary for raising the Breakwater so much higher than was originally intended, it would be seen, that the actual cost of the work was £290,000 below the original estimate.

Sir John Rennie would not trespass further upon the patience of the members; but for any further remarks upon the Plymouth Breakwater, he begged to refer to his published account of that national work, in which, he believed, that satisfactory answers would be found for every objection that could be raised.*

With respect to Kingstown Harbour, nothing could be more erroneous than the reported observation of Colonel Jones, "that notwithstanding an expenditure of £800,000, it was as insecure as before." The same system had been adopted there as at Plymouth, and had as completely answered, when the work was properly carried into effect. If the system of building a vertical wall of masonry had been adopted, the time of execution and the expense of the work, would both have been enormously increased, and the cost of the repairs would have been augmented.

The allusion to this subject induced Sir John Rennie to make a few passing remarks upon certain changes which had been made in

* *Vide* An Historical, Practical, and Theoretical Account of the Breakwater in Plymouth Sound. By Sir John Rennie, F.R.S., F.A.S., F.G.S., Pres. Inst. C.E., folio, plates. London, 1847.

the original design of Kingstown Harbour, as it was left by the late Mr. Rennie. These, he must contend, had materially detracted from the benefits which would otherwise have been conferred. They were made under the direction of the Commissioners of Public Works, when Sir John Burgoyne was Chairman of the Board. Sir John Rennie had pointed out the objections to them at the time, and the result had justified his anticipations. In the first place, the entrance had been altered, so that during easterly gales such a heavy sea set in, that vessels lying at anchor in the harbour were greatly and unnecessarily exposed, and several had actually been driven ashore, and wrecked. Secondly, a vertical wall of masonry had been projected a considerable distance into the centre of the harbour, in front of the entrance, for the purpose of forming a landing-jetty for the packets. The line of shore, in that particular part of the harbour, was, if anything, too much advanced, before the erection of the jetty, or wall before mentioned. The sloping form of the rocks, however, served in some degree to check and disperse the waves; but the new wall, by projecting further into the harbour, from its vertical form, exposed as it was to the impact of the waves, from the altered entrance, created such agitation in that important part of the harbour, that the packets experienced the greatest difficulty in lying alongside it, during heavy easterly gales. Thus the very object of the wall, which was constructed at a very great expense, had been to a great extent defeated, at the very time when it was most required. Thirdly, the old harbour of Dunleary was expressly included in the original design, as it contained the only portion of flat sloping shore where disabled vessels could run and beach upon; it served moreover as an excellent place, where any waves which might enter the harbour during easterly gales could expend themselves, and thus tend to tranquillize the other parts of the harbour; it was, therefore, considered of the utmost importance, that it should be preserved; but, notwithstanding these advantages, the Dublin and Kingstown Railway Company had been permitted to construct, across that part of the harbour, a solid embankment, at a slope of about two to one, thus abridging the valuable space, and at the same time materially increasing the general agitation within. This might readily have been avoided, by directing the railway along the shore, or even carrying it upon an open viaduct, which, by means of Mitchell's screw-piles, or other method, would have been very practicable, and not at all expensive. The whole of these alterations were, in Sir John Rennie's opinion, very injudicious, and had materially injured the harbour. This was the more to be lamented, because the whole of the objects, intended to

have been gained by the alterations, might have been obtained in a more effectual manner without creating the evils which had been alluded to.

Then, as regarded Howth, the flat rubble slope had answered very well, and it still remained to be proved, whether Howth was not the proper station for the packets. As to the harbour of Donaghadee, the flat slope there had also stood very well; and it was only at the spot where the vertical masonry wall of the east pier head, (which was necessary in that small harbour,) was joined into the flat slope, that a few of the rubble blocks were displaced, before the glacis was quite finished; these had since been replaced, and the rubble glacis, after being paved at a trifling expense, had stood well. It should be recollected also, that the Harbour of Donaghadee had been completed for £15,000 below the original estimate, and that sum was devoted to constructing the east pier 10 feet wider than had been originally intended.

As to Ardglass: the stone of which the pier was built, was of a soft slaty schistose nature, and would not resist the effect of the waves; this he had pointed out at the time, and had recommended the employment of other stone, which was better adapted for the purpose. His advice, however, was not followed; the work, moreover, was left in an unfinished state, exposed to the full effect of storms, and Sir John Rennie had expressly pointed out, in writing, that unless it was finished in a proper manner, it would not stand; but this was not attended to, and the natural consequence was, as had been stated by the Noble Lord, that it was considerably injured.

With respect to Portrush: that harbour was designed and constructed by Sir John Rennie. Both piers were carried out to their full extent, in about eighteen months, by depositing blocks of rubble. The establishment was then broken up, and, instead of feeding the slopes of the piers, from time to time, with fresh rubble, as fast as it was drawn down by the waves, in the process of consolidation, and until it had obtained the requisite angle of repose, nothing was ever done; consequently, the slopes could not be expected to remain permanent. In fact, the work was never finished; but, after all, what was the result? A harbour, having two piers, with an entrance between them of about 13 feet deep, at low water of spring tides, enclosing a space of five imperial acres, at low water, was erected in a most exposed situation, and so far completed, for the small sum of about £16,000; and, according to the Report of Messrs. Stevenson (of Edinburgh), a further sum of only £5,000 was required to complete it; in fact, Sir John Rennie did

not know a case, where so much accommodation had been obtained for so small a sum.

He must contend, that this harbour was a most complete answer to the objections against the rubble system; for had a vertical wall of masonry system been adopted, the work would have cost at least four times the amount actually expended, and would not have answered so well; in fact, the construction of the harbour could not have been attempted.

With regard to Dunmore: that pier was built of soft bad sandstone, originally, Sir John Rennie believed, with a vertical wall of masonry, but it failed; a glacis, or flat sloping wall, was then added to the outside; that, although not well executed, had been more effective than the original vertical wall, and, therefore, that pier should rather be quoted as an example in favour of the inclined, or flat slope, instead of being adduced as an argument against it.

With regard to the breakwater at Cherbourg: the failures there arose from the rubble, originally employed, being composed of blocks of too small dimensions. As soon, however, as materials of proper sizes were employed, the rubble system answered very well; a vertical wall of masonry had subsequently been raised upon the top of it, and it remained to be proved, how far it would answer. It now required constant protection, by the addition of rubble, placed outside, without which, it would not stand; and it was stated, that during heavy gales, the waves broke so furiously against the upright wall, that it was impossible to approach, or to walk upon it, although it was 10 feet, or 12 feet above the level of high water of spring tides. Considerable alterations were still requisite, before it could be made to answer the intended object.

With respect to the contemplated project of making a refuge harbour in Dover Bay: Sir John Rennie had explained his views on the subject so fully, in his Report to the Admiralty,* that he could not add anything further to them. In fact, the more he considered the Report of the Tidal Harbour Commissioners, upon that subject, the more he was inclined to adhere to the opinions expressed in his Report. He believed, that if ever the plan was carried out to the extent contemplated by the Commissioners, the cost would, certainly, not be less than he had stated; but would, probably, greatly exceed it. Mr. Walker had stated, that rubble from the Channel Islands, or from Portland, would be so very expensive, that a different system of construction must be adopted. Now it must be

* *Vide* Minutes of Evidence on the Harbour of Refuge to be constructed in Dover Bay.

recollected, that the argument which applied to the rubble, would apply with almost equal effect to the masonry; and that a cubic yard of the latter would cost very much more than a cubic yard of the former.*

Sir John Rennie thought, the protest of Sir Howard Douglas was an extremely able production, and reflected the highest credit upon that distinguished officer. The arguments adduced by him, both as to theory and practice, appeared, for the most part, unanswerable.†

Sir William Symonds' protest, though short, contained much sound sense, particularly his observations relative to the 'gregale,' during northerly gales, upon the perpendicular rocks forming the entrance to Malta Harbour.‡ Sir John Rennie had, himself, witnessed their effect in March, 1826; when large portions of the vertical masonry walls of the great bastion of Ricogali, were undermined and blown up by the waves, and were only restored at great cost.

He apologized for having occupied so much of the time of the meeting, but he trusted, that he had, in some degree, removed the objections to the rubble system, and had proved that the cases quoted by the Noble Lord, in favour of the vertical walls told completely in the opposite direction.

Sir John Rennie did not, however, mean to assert that there might not be many cases, where nearly vertical masonry could be judiciously employed; in fact, he had adopted the system in several instances, and the piers so constructed had completely answered their object.

He could not conclude without again thanking the Noble Lord for his valuable Paper, and expressing the hope, (in which he was sure the whole of the Institution would join,) that his Lordship would continue to bring Papers before them, and that they should have frequent opportunities of discussing the great engineering works of Great Britain.

Mr. RENDEL, *V.P.*, joined his acknowledgments to those of the preceding speakers, for the excellent Paper that had been read, and which would do honour to any Engineer. He would only occupy the time of the meeting by justifying the accuracy of his estimate of the vacuity in the Plymouth Breakwater, and would merely state

* *Vide* Reports and Plans for a proposed Harbour in Dover Bay, No. 4. London, 1845.

† *Vide* Papers relating to the Harbour of Refuge Commission of 1846, on the several modes of construction referred to the Commission for their opinion, pp. 3–48.

‡ *Vide* ditto, ditto, pp. 1–3.

how he arrived at the conclusions he had expressed elsewhere. He ascertained the absolute cubic contents of the Breakwater, and the total weight of stone delivered upon it; then, as it was well known, that 13 cubic feet of Plymouth marble weighed one ton, and he found that weight was made to occupy 19 feet, or 20 feet of cubic space, he was justified in drawing the conclusion as to the amount of vacuity. His opinion was further strengthened, by seeing the heaps of small stone left behind in quarrying the material; and he must contend, that a greater quantity of small stone would have materially assisted in consolidating the structure, if it had been employed with the larger blocks, so as to have filled up the interstices.

The EARL of LOVELACE expressed his thanks to the meeting for the attention given to his Paper, to Mr. Manby, the Secretary, for the assistance he had rendered in its production, and for the excellent spirit with which the apparent strictures had been received. The members must be aware that the Blue-Books were the authorities whence his information had been drawn, and he was gratified, that his observations should have been the means of eliciting such complete refutations, to many of the statements he had extracted. Sir John Rennie's explanations had generally disposed of the objections that had been raised, and he now fully appreciated the force of the arguments against adopting any given form of sea-defences for all situations.

He was not at all aware, and had never seen it stated, that the original design for the Plymouth Breakwater only contemplated its reaching up to half-tide level; that explained in a great degree the increased expense, and it was not to be wondered at, that during the progress of the works, it had been considered necessary to finish them, in a manner which was scarcely contemplated at the commencement.

He would not further occupy the time of the meeting, but he could not sit down without alluding to Mr. Walker's remarks, as to Engineers not being raised to the Peerage, and he would remind him, that his late position of President of the Institution of Civil Engineers, was one of which he might justly be prouder than of any Peerage, hereditary, or created, for he had presided over a body of men, whose works, like the Pyramids of Egypt, or the Temples of Dendera, would survive all record of their designer, and even of the language of the time of their construction. And when he saw the ports and harbours, the general improvement of the coast and rivers, the tunnel beneath the Thames, the suspension and tubular bridges spanning arms of the sea, the apertures pierced through

mountains, for the convenience of the commerce and traffic of the country, and the wonderful inventions and improvements in all branches of Science and the Arts, he thought the Engineer might, on the completion of each of the stupendous works which characterized the present time, use with pride the words of the poet,*—

> Jamque opus exegi, quod non Jovis ira, nec ignes,
> Nec poterit ferrum, nec edax abolere vetustas.

And even add—

> ——— nomenque erit indelebile nostrum.

Major-General PASLEY said, that his predilection had been in favour of long slopes for sea walls and defences, until he heard the Paper by Colonel Harry D. Jones in 1842.† The arguments and examples there given, induced him to make further researches, and he became a convert to the theory of vertical walls in deep water. The duration of the Edystone and Bell Rock Lighthouses, was a strong argument in favour of the forms there employed, and the statement he had made on a recent occasion, ‡ relative to the walls on the South Devon Railway, might be also used as an argument. The majority of the Commissioners appeared to be in favour of the vertical form, after hearing the evidence of all the best authorities on both sides of the question.

After the form was settled, the next questions appeared to be, the materials of which the defences should be composed, and the method of building. General Pasley was convinced, that blocks of concrete, formed of good hydraulic lime, or cement, and laid from diving-bells, might be advantageously used nearly up to low-water mark, and above that line, granite should be employed. The motion of the waves, even in the heaviest weather, did not extend deeper than a few feet from the surface of low-water mark.

Mr. J. MURRAY said, it was stated by writers on physics, that if the depth of water was sufficient to allow the waves to oscillate, they could have no progressive motion: each wave being kept in its place by the action of the others around it.

Hence the existence of coral reefs in deep seas, where it might be supposed, that they could not resist the shocks to which they were exposed. These reefs opposed a nearly perpendicular surface to the force of the waves; their windward sides having sand and large masses of coral thrown up by the breakers, which were said greatly to exceed those on our shores.

---

* *Vide* Ovidii Metamorph., lib. xv.

† *Vide* Minutes of Proceedings Inst. C.E., 1842, vol. ii. p. 124.

‡ *Vide* Minutes of Proceedings Inst. C.E., 1848, vol. vii. p. 193.

The coast of Norway, which was in general bold and steep, with a depth of water close to the rock of from 100 to 400 fathoms, possessed a striking peculiarity in its configuration, inasmuch as it had an outer and an inner line of coast; the latter was the shore of the mainland, and the former was formed by a countless number of rocky islets of all dimensions; within was smooth and deep water, even when the sea was strongly agitated without. The rocks of gneiss and mica schist were usually hard, and were slowly decomposed, yet they had been cut up by the long swell of the Atlantic, which struck the rocky coast with violence: and thus the peculiar fiords and narrow channels had been formed.

The western coasts of Ireland and Scotland were somewhat analogous to that of Norway; bold, rocky, and deeply indented with creeks and inlets. Soundings, however, were met with on approaching the land, and this shelving shore prevented, or retarded the oscillation, and the deep-water waves, not being balanced by those in the shallower water, acquired a progressive motion.

Skerryvore Lighthouse was situated on an exposed rock on the western coast of Scotland, but within the line of soundings of 60 fathoms; and there some observations had been made by Mr. Alan Stevenson, on the strength of the waves. Although Mr. Murray was not quite convinced of the accuracy of the dynamometer employed, yet considerable reliance might, he thought, be placed on it. The greatest result recorded, was a pressure of 6,083 lbs. on a square foot; the average results of the six winter months of 1843 and 1844 being equal to 2,086 lbs. per square foot. Now, according to Leslie,* this made the velocity of the waves in a gale at Skerryvore to be 55 miles an hour, and in the ordinary seasons of winter, 32 miles per hour.

The line of soundings of 60 fathoms, extended across the mouth of the British Channel, from Brest to the Scilly Isles, gradually shoaling to the Straits of Dover, where the greatest depth did not exceed 20 fathoms. In this comparatively shoal water, the tidal waves must be those of progression, and were consequently percussive; therefore, obstacles exposed to them, like breakwaters, must be made sufficiently strong to resist their impact.

As instances of injury sustained by nearly perpendicular walls, he must state, that the sea sometimes struck the new North Pier Head at Sunderland, with great violence, and the old Pier Head, built about the year 1800, adjacent to the Lighthouse, though tolerably well constructed, was destroyed during a storm.

---

* *Vide* Leslie's Elements of Natural Philosophy.

In 1843 a breach of 40 feet in width was made, in the nearly perpendicular pier-head of Port Patrick Harbour, at a depth of from 20 feet to 25 feet below high water, leaving the foundation of the Lighthouse exposed and in great jeopardy.

At Whitehaven Pier the waves struck it laterally with great violence, and were thrown over it in the form of a clear sheet of water. Such was also the case at the Cobb Wall at Lyme Regis, although it was greatly protected by an extent of shelving rocks.

A very heavy sea struck upon the Chesil Bank, which extended from the Isle of Portland westward for a distance of upwards of seventeen miles. The pebbles of which it was formed, were generally about the size of an egg, at the Isle of Portland, while at Bridport, (to the westward,) they were scarcely larger than peas. Its section was also peculiar. And from the outline, as also from that of the shore at Madras, it was evident, that the tendency of the action of the waves, in retreating, was to form nearly regular steps. Much of the stability of the Plymouth Breakwater was due to the wide berm, or benching, on its seaward side.

While constructing the rubble glacis, both at the south and north piers of Sunderland and at Warkworth, almost every separate stone was laid by the action of the waves at a regular slope, nearly approaching 45° with the horizon. The masses of magnesian limestone which were now being deposited by the action of the waves on the south rocks at Sunderland, were lifted by the sea and laid in a similar manner, and also in a form approaching to regular steps. Mr. Murray was, therefore, of opinion, that the sea face of an exposed breakwater in Dover Bay ought to have a stepped sloping glacis, terminating with a cycloidal curved parapet.

It had been stated by Engineers, and was believed by many, that the agitation of the sea was only felt at a little distance below the surface.

Brémontier said, that the agitation in storms, extended in many cases to very great depths; on the sandbank of Newfoundland it descended even to 60 fathoms.

To the south of the Cape of Good Hope the sea was broken, where the depth was more than 100 fathoms.

M. Virla found the velocity, in great waves of 130 feet in length, to be 66 feet per second, or 45 miles an hour, and the vertical depth of the agitation to be 54 fathoms.

M. Viennois had made some observations on wades, in the Bay of Biscay, and found, that the depth of the agitation, during storms, was from 164 fathoms to 212 fathoms, and that the velocity of the oscillation was from 30 miles to 45 miles per hour.

With these facts in evidence, it would surely be wise to pause before placing a breakwater with vertical sides in Dover Bay.

Major-General PASLEY doubted whether the French Engineers, whose authority had been quoted, had ever descended in a diving-bell, or a diving-helmet; and in default of evidence to that effect, he must be permitted to reject their opinions.

Mr. J. MURRAY said, that he had frequently descended in the diving-bell, and although he knew, that, under ordinary circumstances, the agitation of light winds at the surface, did not influence the greater depths, yet he had, on the contrary, found considerable agitation below, when the surface was apparently tranquil. Whenever the bell was heaved and became wet inside, a storm invariably followed. This he attributed to the movement of the great body of water in the Atlantic, forcing up the under-current.

Major-General PASLEY attributed the unsteadiness of diving-bells generally to their improper form; he never could use them advantageously, until he adapted pointed ends to them. In shallow water they might be used, but in deep water, men in diving-helmets could do much better work.

Sir JOHN RENNIE reverted to the facts of the construction of the Plymouth Breakwater, and, as a passing reply to General Pasley, Sir John was of opinion, not only that diving-bells were preferable, but that divers in helmets would not have been able to do the work at all.

It was considered desirable to construct the Breakwater with the utmost speed, and accordingly, in eighteen months from the date of its commencement, it afforded shelter under its lee, to a ship of one hundred and twenty guns. Now if the sections of the Breakwater, taken at many different periods, were examined,* it would be seen, that the sea had only taken away portions of the covering, and carried the materials over to the leeward side, giving the seaward slope, that inclination due to the action it had to support; but the blocks were not conveyed to any considerable distance.

If the whole history of the Breakwater was considered, as given in his recent account of it, it would be perceived, that instead of exceeding the estimate, it had been completed within the calculated cost. The term "disastrous" could not, therefore, he contended, be correctly applied to that work.

Mr. J. SCOTT RUSSELL thought, that Lord Lovelace had done good service, not only in producing so interesting a Paper, but in eliciting opinions from the eminent Engineers who had spoken upon

* *Vide* Rennie's Plymouth Breakwater, Plates 13 to 17, and 20 to 22.

it. Mr. Russell thought, that neither vertical walls, nor sloping sea-defences, should be considered irrespective of the three great questions, of the position of the work, the nature of the material to be employed, and the total cost. Now as to the amount of force stated to be acting against the Edystone and the Bell Rock; if their form and mode of construction, by bonding and rendering them almost monolithic, was to be adopted for sea-defences, half-a-dozen such masses would cost as much as the Plymouth Breakwater; that kind of construction was, therefore, evidently inappropriate for sea-defences, and that which apparently offered the greatest facilities, under ordinary circumstances, was that which had been adopted at the Plymouth Breakwater, where the weight and consistency of the mass formed its safeguard.

From what had been stated, it might be inferred, that a vertical wall would deflect the waves without breaking, and that a smaller quantity of material was employed; but as the foundations required to be well laid, at considerable depth, great care was necessary in the construction, and superior materials must be employed, therefore the cost would, in ordinary positions, be enhanced.

Sloping sea-defences were liable to run into extremes, either in having too gentle, or too rapid a face towards the sea. If large blocks of stone were at hand, with smaller materials to fill up the interstices, it was easy to place them, in due proportion, at an angle of 45°, which was the best inclination; because if the slope was flatter, a portion of the advantage of the superincumbent weight, or pressure, of the upper stones was lost, and on a nearer approach to the vertical, if the lower stones were drawn out, by the retiring wave, the upper courses fell. In a vertical wall the greatest effect of weight was obtained, and if the foundation did not give way, the faces of the stones being smooth, and the joints well filled in, it would stand; but the angle of 45° must, he contended, be considered, generally, as that which offered the greatest amount of advantage under ordinary circumstances.

Mr. WALKER confirmed Mr. Russell's views; there could not, in practice, be any general rule; all descriptions of works had failed, and would fail again, under particular circumstances. The forms of all sea-defences must be adapted to the various considerations named by Mr. Russell, and must vary with them. For instance, Mr. Walker was now constructing a vertical wall, a long slope, and a sea-defence at an angle of 45°, in three different positions, and he saw no reason to doubt the success of all the three; in fact, they would stand, or fall, as they were well, or ill constructed, and their

forms were well, or ill adapted to resist the forces to which they were opposed.

If a form like that of the Chesil Bank was adopted at Dover, the work would never be finished, with any ordinary means, or at any reasonable expense, as the material would cost nearly three times as much as that used at Plymouth, and unless a whole fleet was employed to convey the stones, the necessary quantity could not be obtained; therefore the pier that had been commenced was nearly vertical, particularly as it was necessary, that vessels should come alongside to load and discharge their cargoes.

Mr. Walker was of opinion, that however good, or successful any work might be, it should not be blindly used as an argument, or as a precedent for any other construction; it was the business of the Civil Engineer to adapt his design to the locality, the material, and the cost, and to use the experience he had acquired, or the examples set him by others, to prevent his falling into errors. Such also was the great use of the discussions at the Institution, and he would conclude by again thanking the Earl of Lovelace for bringing the subject before the Members, and trusted, that during the next Session his Lordship would be very frequently found among the Engineers, and contributing Papers to the Institution.

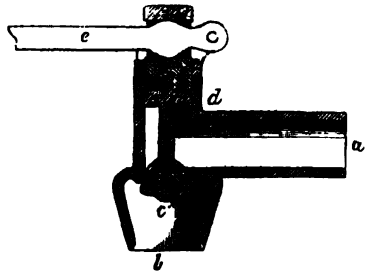
Lambert's Flexible Diaphragm Water-Valves.

After the Meeting, Mr. Lambert exhibited and described his flexible diaphragm water-valves. Two flexible diaphragms, c and cx, are used, confined at the edges by screws i, the centre portion being moveable and connected by a spindle, so that they move simultaneously when acted upon by the lever e.

The chief novelty of the invention consists in the application of the lower diaphragm cx, as a surface to be pressed upon by the column of water in the supply-pipe, and thus aid in keeping the valve tight, by holding the upper diaphragm c to its seating. The area of cx being greater than the area of the opening, or outlet closed by c, it follows, that as soon as the diaphragm c is pressed upon, the valve-seating, by means of the lever e, assisted by the screw in the cover d, (or otherwise,) is there held by the excess of pressure upon the area cx, and thus by adapting the area of cx to the height of the column of water, it may be made to open as easily under a pressure of 500 feet, as of 50 feet. The upper diaphragm c, in addition to its making the valve-joint, serves the purpose of a

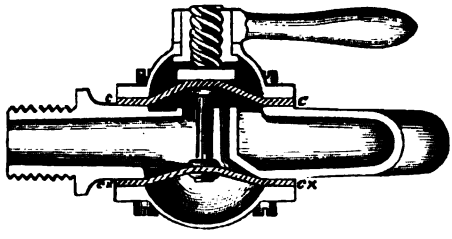
stuffing-box, so that it is impossible for any leakage to take place, so long as the India-rubber is sound; and there being an almost perfect absence of friction, it is necessarily very durable.

Fig. 1.



Longitudinal section, showing the valve open.

Fig. 2.



Longitudinal section of cistern, or ball-valve, closed.

In this valve a piston is used instead of the diaphragm cx, and it is found to answer exceedingly well under any pressure.

June 27, 1848.

JOSHUA FIELD, President, in the Chair.

The following Candidate was balloted for and duly elected:—Captain John Milligan Laws, R.N., as an Associate.

The discussion upon the Paper, No. 796, "On Harbours of Refuge," by The Right Hon. the Earl of Lovelace, being resumed, was continued to such a length as to preclude the reading of any other communication.

Mr. FIELD,—President,—addressed the Meeting, congratulating the Institution, upon the Papers read during the Session, having given evidence of great care and talent, and upon the more numerous attendance at the discussions, which demonstrated the increased interest taken in them, not only by the Members themselves, but by gentlemen of kindred pursuits and professions. He hoped that, during the recess, the younger Members of the profession would prepare for the Institution descriptions and drawings of any works on which they might be engaged, as such Papers formed a valuable and important part of the records of the Society.

He expressed his gratitude to the Council for the kind and able assistance afforded to him in the discharge of his duties as President, —to Mr. Manby, the Secretary, for his untiring zeal in every department of the service of the Institution,—and to the Members generally, for the support given to him in the Chair, and the satisfaction they had expressed with the arrangements on the occasion of the Conversazione, especially as it was the first which had been held in the rooms of the Institution.

Being duly moved and seconded, it was then resolved,—That the cordial thanks of the Meeting be offered to Mr. Joshua Field, the President, for his able and urbane conduct in the Chair, and for his unwearied attention to the interests of the Institution.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1848.

Accounts, abstract of receipts and expenditure, from the 1st January to the 31st December, 1847, 20.

Adams, E., elected associate, 184.

Address of Sir J. Rennie, *President*, to the annual general meeting, 27.— *Vide* also Rennie.

———— J. Field, *President*, 32.— *Vide* also Field.

Annual general meeting, 73.

——— Report, 1.—Ditto read, and ordered to be printed, 74.— *Vide* Report.

Atmospheric railway, proposed series of experiments upon the, noticed in the Annual Report, 16.

Baker, W., elected member, 184.

Bann reservoirs, County Down, Ireland, description of the, 251.—Character of the Mourne Mountains, in which the River Bann rises, 251.—Liability to devastating floods, rendering remedial measures necessary, 252.—Principle of the Act, obtained in 1836, for the construction of the reservoirs, and for regulating the manner in which the money was to be raised, and the rates to be levied, 252.—Projected impounding reservoirs at Lough Island Reavy and at Deer's Meadow, and auxiliary reservoir at Corbet Lough, 253.—Detailed description of the formation of the reservoir at Lough Island Reavy, 254.—Shallow lake selected as the site, 254.—Field of fossil confervæ in the bottom of the lake, 254.—Difficulty in determining the proper extent of the reservoir, 255.—Details of the mode of construction of four embankments for retaining the water in the lake, or reservoir, above its summer level, 255.—Culvert under the principal embankment, for discharging the water, 257.—Mortar prepared from the mountain limestone from the Isle of Man, 258.—Leaks in the outer culvert, attributed to the rubble backing behind the side walls, which had been substituted, without authority, for the puddle prescribed in the specification, 259.—Mode in which the leaks were stopped, 260.—Masonry of the fore-bay of the discharging-chamber, 260.—Discharge pipes and valves, 261.—Waste weir for discharging the surplus water, 261.—Bridge across the feeder from the River Muddock, 262.—Diversion of the River Muddock, and construction of the Moneyscalp and Slievenalargy feeders, to bring the requisite supply of water to the reservoir, 263.—Cost

of the works, 264.—Particulars and calculations of the amount of rain, and the available supply, 264.—Rain-gauge observations at Lough Island Reavy, and on Spelga, 265.—Account of the manner in which it is proposed to work the Corbet Lough Reservoir in connection with that at Lough Island Reavy, 266.—Objects of the Corbet Lough Reservoir, 268.—Detailed description of the works for the formation of ditto, 268.—Advantages gained by its construction, and effect upon the regular power of the river, 269.—Water-course to convey the water of the river to the reservoir, 271.—Side-weir for withdrawing the water from the river, 271.—Stop-gates for regulating the flow down the water-course, 271.—Bridges across the water-course, 272.—Details of the embankment of the reservoir, 272.—Discharge-sluices and discharging apparatus, 272.—Self-acting flood-gates, 272.—Waste-weir, 273.—Water-course for conveying the water from the reservoir, 273.—Cost of the works, 274.—Unauthorized publication of the drawings illustrating, and extracts from, Mr. Bateman's Paper, noticed in the Annual Report, 17.

Barry, C., remarks as to artificial stone, with a silica base, 66.

Bateman, J. F., unauthorized publication of the drawings illustrating, and extracts from, his Paper, "Description of the Bann Reservoirs," noticed in the Annual Report, 17.—Remarks as to the materials for submarine constructions, and as to the pitched face of the Loch Foyle embankment, 198.—Description of the Bann Reservoirs, County Down, Ireland, 251.—Remarks as to the advantages of ditto to the mill-owners, and as to the self-acting balance flood-gates, 274.—Ditto as to Lough Island Reavy Reservoir, 274.—Ditto as to the amount of rainfall compared with the water flowing off the ground in different districts, 275.—Ditto as to comparisons between the rainfall on high and low lands, 277.—Ditto as to extracts from Mr. Miller's Report, as to the gradation in the quantity of rain at different elevations above the sea, and the unequal distribution of rain in the climate of Great Britain, 277.—Ditto as to the rainfall in the Longdendale district, and the quantity of water flowing off the ground, 284.—Ditto as to observations made with funnel rain-gauges, at Woodhead, in Longdendale, at Todd's Brook, and at Combs, 287.—Ditto as to the changes in the estuaries of the Exe and the Sid, from the action and movement of shingle, and of the material forming the coast, 361.

Beanlands, A., on railway junctions, 204.—Elected associate, 366.

Beardmore, N., remarks as to the amount of rain falling in hilly districts, particularly in the Glencorse district of the Pentlands, 285.—Ditto as to the storage-room required in proportion to the area of drainage-ground, 286.—Ditto as to the alternate elevations and depressions of the coast of Devon and Cornwall, and as to the Chesil Bank, 361.

Bidder, G. P., remarks as to the resistances to railway trains, and as to the mode of conducting experiments for ascertaining the, 302, 307, 308, 321.—Ditto as to experiments on inclined planes, 312.

Boiler, tubular, results of the application of the, to marine engines, noticed in the address of Mr. J. Field, *President*, 40.

Borthwick, M. A., remarks as to the Dymchurch wall, 195.

Braithwaite, F., remarks as to objections advanced against the commercial application of sewage manure, 101.—Ditto as to the practicability, in a commercial point of view, of utilizing the sewage water of London, 102.—Ditto as to the resistances to railway trains, and as to the mode of conducting experiments for ascertaining the, 324.

Brande, Prof., remarks as to the change suffered by cast-iron, when exposed to the action of salt water, or in mines, &c., 157.

Breakwaters, floating, proposed as a means of insuring safety from the weather, 368 *et seq.*

Bridge for carrying the South Wales Railway across the River Wye, at Chepstow, experiment near the site of the, to ascertain the desirability of employing cast-iron cylinders with a helical flange or screw, for the foundations, 137.

Brooks, W. A., remarks as to the system of screw moorings in the Tyne, and the apparatus employed for inserting them, 132.

Brunel, I. K., remarks as to dock-entrances, 182.—Ditto as to the injury sustained by a sea wall on the South Devon Railway, 193.—Ditto as to the comparison between vertical and sloping walls for sea defences, 193.—Ditto as to the resistances to railway trains, and as to the mode of conducting experiments for ascertaining the, 299, 308, 318.—Ditto as to sources of error in experiments on inclined planes, 306, 313.

Buckland, the Very Rev. Dean. *Vide* Westminster, the Very Rev. the Dean of.

Building fund, deficiency in the subscriptions to the, 15.

Burnett, Sir W., remarks as to a preparation of chloride, or muriate of zinc, proposed by, as a deodorizing agent, 98.

Bury, T. T., elected associate, 326.

Carpmael, W., remarks as to the structure of the artificial stone, made with a silica base, 70.

Chadwick, E., remarks as to the application of liquid manure on the Mansfield meadows, and on some land near Edinburgh, 95.—Ditto as to the want of resemblance between the produce of the sewers of London, and of Edinburgh, 96.—Ditto as to the value of liquid manure, 96.—Ditto as to presumed exhalations arising from the application of liquid manure, 96.—Ditto as to the results from this mode of manuring, 97.—Ditto as to the expense of the distribution of liquid manure, 97.

Cheffins, C. F., elected associate, 366.

Chubb, J., notice of an iron chest for the transmission of money and valuables on Railways, 185.

Clarke, —, remarks as to screw piles and their uses, 144.

Clegg, S. jun., elected member, 184.

Coast, English, observations on the causes that are in constant operation tending to alter the outline of the, to affect the entrances of the rivers and harbours, and to form shoals and deeps in the bed of the sea, 327.—Works consulted, 327.—Causes in constant operation, with more or less intensity, 328.—Origin and progress of rivers, 328.—Earthy and other matters brought down by fresh water streams and rivers, 329.—Nature and action of waves, 329.—Distinctive characters of the wave of translation, and of the undulating wave, 330.—Mr. Scott Russell's opinion as to the tidal wave being the great wave of translation, 331.—Effect of the tidal waters running alternately into and out of rivers and estuaries, 332.—Ditto of the tidal waves in the open sea, 332.—Extract from Mr. Stevenson's paper on the bed of the German Ocean, 332.—Course of a tidal wave in the English Channel, 333.—Consequences of the ebb current being stronger than the flood, 333.—Peculiarities in the effects along the coasts, 334.—The Races of Alderney and Portland, 334.—The effects of the tide round the Isle of Wight, 335.—

Times of high water on the coast, at the Isle of Wight, on the opposite French coast, and in the North Sea, 336.—Was England ever connected with the Continent at the Straits of Dover? 338.—General action of the tidal wave in the Channel, 339.—Are the Romney Marshes a consequence of the breaking through of the sea at the Straits of Dover? 339.—Effects observable from the action of wind-waves on the beach, 340.—Best direction for the construction of groynes for the collection of shingle, 344.—The Chesil Beach and Dungeness, 344.—Effect of the tidal wave in aiding encroachments upon the coast, 344.—Influence exerted by streams, rivulets, rivers, and estuaries, running inland along the coast, 345.—Result of continued encroachments of the sea upon the land in the Great Western Bay, 346.—Geology of the neighbourhood, 347.—Manner in which the changes have been brought about in the Great Western Bay, 348.—Process of encroachment in this bay still going on, 350.—Examination of the present state of the Exe and the Teign, 351.—Various actions to which the material of the coast is subjected, 355.—Appendix, Table showing the times of high water on full and change, and the rises of spring and neap tides, in feet, at different places, 358.

Concrete, remarks as to the formation of, 70.

Conversazione, President's, resolution as to holding it at the Institution, 291. —Notice of, 366.

Council and Telford premiums awarded, Session 1847, 2, 22, 74.—List of subjects for, Session 1848, 23.

——— remarks, in the Annual Report, as to the balloting list for members of council, 18.—Ditto, in the address of Sir J. Rennie, *President*, particularly as to the biennial change of President, and as to the nomination of Mr. Field for that office, 27.—List of, for 1848, 56, 75.—List of the attendances of the members of, read, 73.—Ballot for, 73.—Annual Report of, read, 74.—Annual Report, 1.—Vote of thanks to, 74.

Counter, engine, on an improved principle, description of an, 71.

Crampton, T. R., remarks as to the resistances to railway trains, 320.

Crane, P. M., elected associate, 75.

Croker, B. W., remarks as to the methods for rendering rivers navigable, by means of long diagonal weirs, with side locks and gates, and by means of side embankments and facing to the original shores, 246.—Ditto as to the plans resorted to for improving the rivers in Hungary, particularly the Danube, which was formerly effected by spurs for deepening the channel, but was now effected by reclaiming the side arms, 247.—Ditto as to the construction of weirs on the Altmühl, 249.—Ditto as to works for controlling the waters of the River Theiss, 249.—Ditto ditto the White Körös, 249.

Cubitt, W., *V. P.*, remarks as to screw-piles and moorings, 144.—Ditto as to dock entrances, 178.—Ditto ditto, particularly as to that at the Duke's Dock, Liverpool, 180.—Ditto as to the effect of long oblique weirs for improving the regime of a river, 245.—Ditto as to the systems adopted on the Clyde, and on the Tees, 246.

Cundy, T., jun., elected associate, 75.

Carrey, H., elected associate, 250.

Dalrymple, G. S., elected member, 326.

Davison, R., appointed one of the scrutineers of the ballot for Council, 73.—Vote of thanks to, 75.—Ditto as to the substitution of gun-metal gratings for cast-iron ones, at Messrs. Hanbury's Brewery, 158.

Davy, Sir Humphry, remarks as to his investigations on gas-lighting, 99.

De la Beche, Sir H., remarks as to the manufacture of artificial stone, with a silica base, 67.

Disinfecting and deodorizing agents, remarks as to various, for neutralizing and destroying noxious effluvia, and counteracting putrescence, 97.

Dock-entrances—on the formation of entrances to wet and dry docks, situated upon a tideway; illustrated by the principal examples in the Port of London, 159.—Practice as to docking a ship in the port of London, 159.—Blackwall entrance of the East India Docks, 159.—Docks and slips at Messrs. Wigram's and Messrs. Green's, Blackwall, 160.—Blackwall entrances of the West India Docks and of the City Canal, 160.—Western, or upper ditto ditto, 161.—Direction of the building-slips and of the graving-docks at Woolwich Dockyard, 161.—Ditto at Deptford Dockyard, 162.—Entrance-locks to the East Country Dock, and to the Commercial Docks, 162.—Messrs. Dowson's graving-dock at Limehouse, 163.—Regent's Canal entrance-lock, 163.—Lavender graving-dock, Rotherhithe, 164.—Shadwell entrance of the London Docks, 164.—Extracts from Mr. H. R. Palmer's "Report on the proposed eastern entrance to the London Docks," including remarks on the entrances to the Bristol and the Runcorn Docks, on the docks in the Port of London, and on the entrances to the principal public docks, and the labour entailed at the graving-docks on account of their position, 165.—Entrance to the Grand Surrey Docks and Canal, Rotherhithe, 167.—Central and upper entrances of the London Docks, 168.—St. Saviour's Dock entrance, 168.—St. Katharine's Dock entrance, 168.—Proposed graving-dock, 169.—Proposed wet-dock, 169.—Remarks as to building-slips, 170.—Extracts from the opinions of Mr. Dowson, Mr. Knight, Captain Bond, Captain Evans, Mr. Kinipple, Mr. Green, Mr. Haslip, and Mr. Wigram, on dock entrances in the Port of London, 171.

Donaldson, Professor, remarks as to the manufacture of artificial stone, with a silica base, 63.

Donkin, B., remarks as to the construction of iron lighthouses, 156.

Drainage and sewerage of Bristol, account of the recent improvements in the, 76.—*Vide* also Sewerage.

Drysdale, A., elected associate, 184.

Duncan, T., elected associate, 366.

Elliot, J., elected member, 184.

Engine-counter on an improved principle, description of an, 71.

Engineer, mechanical and civil, remarks in the address of Mr. J. Field, President, as to the connection subsisting between the, and their dependence upon each other, 32.—The mechanical engineer the first to apply the great powers of nature, 33.—As public works, principally for facilitating communication, increased, a separate class of engineers, called 'Civil Engineers,' was established, 34.

England, J., elected member, 184.

Faraday, Dr., remarks as to the manufacture of artificial stone, with a silica base, 60, 61.—Ditto as to the difference between the composition and the manipulation of terra-cotta and this artificial stone, 64.

Farey, J., remarks as to the properties of the artificial stone, made with a silica

base, and its comparison with terra-cotta, 63.—Ditto as to engine-counters, 73.—Ditto as to the Maplin Sand and Fleetwood-on-Wyre Lighthouses, 156.—Ditto as to the change suffered by cast-iron, when in contact with gun-metal, and under the influence of high-pressure steam, 157.

Field, J., *President*, address of, 32.—Connection subsisting between the mechanical and the civil engineer, and their dependence upon each other, 32.—The mechanical engineer the first to apply the great powers of nature, 33.—As public works, principally for facilitating communication, increased, a separate class of engineers, called 'Civil Engineers,' was established, 34.—Effects of the progressive improvement in the manufacture of iron, 34.—Application of the steam-engine to navigation, 35.—Ship-building in iron, 35, 39.—Supply of towns with water and gas, 36.—Gradual improvement in the tools and apparatus for constructing machinery, 36.—Progress of the marine engine and steam navigation, 38.—High speed attained by the introduction of the tubular boiler, 40.—Reduction in the consumption of fuel, 42.—Introduction of the screw propeller, 42.—Remarks as to engine-counters, 73.—Ditto as to the system of spurs on the Moselle, 244.—Notice of his conversazione, 366.—Remarks on the close of the Session, 418.

Foundations, submarine, on, particularly the screw-pile and moorings, 108.—*Vide* also Screw-pile.

Fowler, H., elected member, 184.

Fox, C., remarks as to the resistances to railway trains, 320.

Garrod, Dr., remarks as to the manufacture of artificial stone, with a silica base, 65, 69.

Gas-lighting, extension of, noticed in the address of Mr. J. Field, President, 36.—Remarks as to, and as to the best form of gas-burner, 85, *et seq.*

Gauge Commissioners, Report of the, remarks as to the, 322, *et seq.*

Giles, F., memoir of, 9.

Glynn, J., remarks as to the decay of cast-iron in coal-mines, 158.—Ditto as to the rainfall in different parts of England, the amount lost by evaporation and absorption, and the quantity flowing off the ground, 275.

Gooch, D., observations on the resistances to railway trains at different velocities (abstract), 292.—Remarks as to ditto, and as to mode of conducting experiments for ascertaining the, 306.—Ditto as to experiments on the speed of trains descending the incline planes of the Great Western Railway, 309, 318.

Government, remarks, in the address of Sir J. Rennie, President, to the Annual General Meeting, as to public works coming under the control and cognizance of the, 30.

Greaves, C., elected member, 326.

Green, J., account of the recent improvements in the drainage and sewerage of Bristol, 76.—Remarks as to the main object of the works, 87.—Ditto as to the Dymchurch wall, or embankment, including particulars as to its construction and dimensions, and the repairs and reconstruction executed after the damage done by the sea in 1803, 194.—Ditto as to the changes in the estuaries of rivers, particularly the Exe, the Axe, and the Sid, from the action and movement of shingle, and of the material forming the coast, 360.

Grosvenor, Lord R., M.P., remarks as to flushing sewers, and as to utilizing the sewage for agricultural purposes, 86.

Harbours and rivers, observations on the causes that are in constant operation tending to alter the outline of the English coast, to affect the entrances of the, and to form shoals and deeps in the bed of the sea, 327. *Vide* also Coast.
Harbours of refuge, on, 366.—Report from the Select Committee of the House of Commons, in 1836, as to the causes of shipwreck, 366.—Committee of the House of Commons appointed in 1843, to inquire into the subject of harbours of refuge, 367.—Opinion of the Duke of Wellington, as to the effect a war with France would have, on the trade passing the coast of Kent, 367.—Two separate objects to be accomplished, safety from the weather, and defence against the enemy, 368.—Floating breakwaters proposed for the former purpose, 368.—Plan suggested by Captain Taylor, 369.—Ditto, Captain Pringle, R.E., 369.—Ditto, Captain Sleigh, R.N., 369.—Ditto, Major Parlby, B.E., 369.—Commission appointed in 1844, to report whether a harbour of refuge in the Channel is desirable, and what should be its site, 370.—Recommendations in the Report, 371.—Three sorts of harbours described, 371.—Disadvantages of an open harbour, covered by a breakwater unconnected with the shore, 372.—Captain Vetch's proposal to utilize the open roadstead of the Downs, by fixing the Brake and the Goodwin Sands, 372.—Sir John Rennie's idea of enclosing the small Downs, by artificially increasing the Brake, 373.—Breakwater at Portland recommended by the Commissioners, 373.—Result of the inquiry instituted by the Commissioners, the construction of a breakwater at Dover, examined, 374.—Evils to be apprehended at Dover, the accumulation of shingle to the westward, and the general deposit of silt, 375.—Opinions of Captain Vetch and Sir H. De la Beche, 376.—Dungeness affords an illustration of the views of the latter, 376.—Pier or breakwater, projecting from the shore at Dover, will probably form a sort of Ness, 377.—Obstacles presented by the silt considered, and opinions of Captain Vetch and Sir H. De la Beche thereon, 378.—Captain Vetch's proposed plan for an insulated breakwater, 378.—Prof. Airy on the probabilities of silting up, under the different conditions of a through current and a single entrance, 378.—Captain Washington's experiments on the quantity of silt held in solution by the water in Dover Bay, 379.—The expense of dredging, 380.—Question of construction considered, 380.—Cherbourg Breakwater, 381.—Mr. Rendel's objections to the Plymouth Breakwater, 381.—Arguments in favour of the long slope, deduced from the harbours of Kingstown, Howth, Ardglass, Donaghadee, Portrush, and Dunmore, 381.—Plymouth Breakwater, 383.—Permanency of a long slope depends upon its being constantly supplied with a succession of materials, 384.—Captain (now Sir William) Denison, R.E., on the best form and materials for the construction of a breakwater, 385.—Mr. Hartley as to the action of the sea on an upright wall, 386.—Captain Vetch ditto, 387.—Prof. Airy ditto, 387.—Sir W. Symonds' views against making a harbour of refuge at Dover, 389.—Sir Howard Douglas' reasons for disagreeing with the recommendations of his colleagues, 389.—Sir H. De la Beche on the action of the sea on coasts, 390.—As to Cherbourg serving to demonstrate the superiority of the principle of the slope, 391.—Mr. Stuart's objections to the solid body in the middle, as at Cherbourg, 391.—Theories of Colonel Emy, especially in his book 'Du Mouvement des Ondes,' and to his advocacy of the long slopes of rubble, 392.—Emy's theory of the 'flot du fond,' 394.—Bremontier and La Coudraye's ideas as to the action of waves, 394.—Mr. Alan Stevenson's marine dynamometer for testing the force of the waves, 395.

Harding, Wyndham, remarks as to the resistances to railway trains, and as to the mode of conducting experiments for ascertaining the, 295, 308, 326.—Ditto ditto, and as to experiments on inclined planes, 315.—Ditto as to the Report of the Gauge Commissioners, 322.
Harris, G. W., elected associate, 184.
Harrison, G., elected associate, 75.
———, J. T., observations on the causes that are in constant operation tending to alter the outline of the English coast, to affect the entrances of the rivers and harbours, and to form shoals and deeps in the bed of the sea, 327.—Remarks as to the island in front of the Warren, 361.—Ditto as to the conveyance of materials by the wave of translation, and as to the traces of submarine forests in the Great Western Bay, 362.
Hawkins, J. J., remarks as to the formation of concrete, 70.
Hawkshaw, J., remarks as to the resistances to railway trains, and as to the mode of conducting experiments for ascertaining the, 325.
Hawksley, T., remarks as to the rainfall in the Rivington district, the amount lost by evaporation and by absorption, and the quantity flowing off the ground, 275, 282.—Ditto as to the amount of water which may be collected into reservoirs, 283.—Ditto as to the greatest fall of rain occurring at the mean height of the rain-cloud, 283.—Ditto as to the proportion between the rainfall and the quantity of water flowing off the ground in different parts of England, 287.
Haywood, W., elected associate, 366.
Holtzapffel, C., memoir of, 14.
Homersham, S. C., remarks as to Lough Island Reavy Reservoir, 274.—Ditto as to the results obtained from funnel rain-gauges in the district of Longdendale, 276.—Ditto as to the want of analogy in the amount of the rainfall in different districts, 280.—Ditto as to the amount of rain among the hills at St. Helena, 282.—Ditto that the amount of rain falling decreases with the altitude, 284.—Ditto as to the amount of water flowing off the ground into the reservoir of the Ashton Water works, 284.—Ditto as to the amount of water yielded for consumption throughout one year, by a reservoir of given capacity, fed from a given area of drainage-ground, 286.
Hughes, E., elected associate, 184.
———, R., elected associate, 250.
Humphrys, E., elected member, 366.

Incline planes, experiments on the speed of trains descending, on the Great Western Railway, remarks as to, 309.
Iron, cast, change suffered by, when exposed to the action of salt water, or in mines, and in various other positions, remarks as to, 157.
——, effects of the progressive improvement in the manufacture of, noticed in the address of Mr. J. Field, President, 34.
—— ship-building, noticed in the address of Mr. J. Field, President, 35, 39.

Jackson, G. B. W., the engineering of the Rhine, including a translation of M. Van den Bergh's Paper, on the improvements of the Moselle, 211.
Jermyn, G. A., appointed one of the scrutineers of the ballot for Council, 73.—Vote of thanks to, 75.

Lambert, T., notice of his flexible diaphragm water-valves, 416.
Laws, Capt., J. M., R.N., elected associate, 417.

Leach, S. W., elected associate, 184.
Ledoyen, M., remarks as to a preparation of nitrate of lead proposed by, as a disinfecting and deodorizing agent, 98.
Lighthouse, Maplin Sand, an account of the, at the mouth of the River Thames, 146.—Principal entrances into the Thames, 146.—The Swin, or King's Channel, on the north, 146.—Mode of construction of ordinary light-vessels, 147.—The Swin Middle light-vessel, 147.—The Sheers light, 148.—Determination to erect a fixed light on the Maplin Sand, 148.—Boring to ascertain its nature and density, 148.—Decision to employ screw-piles for the foundations, 149.—Manner in which they were screwed down into the sand, 149.—Raft, or grating, of timber, formed to secure a foundation for the building, owing to the shifting of the sand, 150.—Superstructure, 151.—Lighting apparatus and lantern, 151.—Appendix, description of the construction, 153.—Ditto, principal dimensions, scantlings, &c., 155.—*Vide* also Screw-pile.
Lights, floating and fixed, remarks as to the comparative merits and expense of, 139, *et seq.*
Lipkens, A., memoir of, 10.
Lloyd, T., remarks as to the propriety of all steam-vessels having counters on board, 73.
Locke, J., M.P., remarks as to the resistances to railway-trains, and as to experiments on inclined planes, 305, 306, 309, 317, 320.
Lovelace, Rt. Hon. the Earl of, on harbours of refuge, 366.—Remarks on ditto, 410.

Machinery, gradual improvement in the tools and apparatus for constructing, noticed in the address of Mr. J. Field, President, 36.
Malcolm, Sir C., remarks as to the rainfall on the Malabar coast of India, 282.
Manby, C., Secretary, vote of thanks to, 74.
Mather, W., and C., notice of their elastic metallic piston, 289.
May, C., remarks as to the porosity of artificial stone, made with a silica base, and of other building materials, 69.—Ditto as to the sewerage of cities and towns, 100.—Ditto as to the entrance to the Ipswich Docks, 178.
M'Clean, J. R., remarks as to the Barrow and Piel sea embankments of the Furness Railway, 201.
M'Cleery, —, remarks as to the fall and other particulars of the Lower Bann, 287.
Memoirs of deceased members, 7.
Miller, J. F., extracts from his Report, as to the gradation in the quantity of rain, at different elevations above the sea, and the unequal distribution of rain in the climate of Great Britain, 277.
Mitchell, A., on submarine foundations, particularly the screw-pile and moorings, 108.—Remarks as to the system of screw-moorings in the Tyne, 135.—Ditto as to the construction of lighthouses, the relative expense of iron and stone, and as to the comparative merits of floating and fixed lights, 140.—Ditto as to the screw-pile pier at Courtown, 142.—Ditto as to depth of penetration of screw-piles, 144. —Ditto as to the terms for the right of using the screw-piles and moorings, 145.
Moorings, screw-pile and, on submarine foundations, particularly the, 108.—*Vide* also Screw-pile.
Moorsom, Capt., remarks as to the economy resulting from the employment of

screw-piles, and as to their use having been hitherto limited by an excessive royalty, 42.—Ditto as to the resistances to railway trains, and as to experiments on inclined planes, 317.

Motion of shingle, sand, &c.—observations on the causes that are in constant operation tending to alter the outline of the English coast, to affect the entrances of the rivers and harbours, and to form shoals and deeps in the bed of the sea, 327.—*Vide* also Coast.

Murray, J., remarks as to screw-moorings, 141.—Ditto as to dock-entrances, particularly of those for the proposed docks at Sunderland, 179, 180.—Ditto as to the abrasion of materials in submarine constructions, the sandstone glacis in the harbour of Walker, the accumulation of shingle by groynes, and the sea-defences on the coasts of Holland, 199.—Ditto as to the proper positions for placing rain-gauges, 277.—Ditto as to the configuration of the coast of Norway, and of the western coasts of Ireland and Scotland, 411.—Ditto as to the strength of the waves at Skerryvore, 412.—Ditto as to instances of injury sustained by nearly perpendicular walls, 412.—Ditto as to the depth below the surface to which the agitation of the sea extends, 413, 414.

Mushet, D., memoir of, 11.

Newlands, J., elected member, 366.

Newton, W., remarks as to the difference between porosity and absorption, and as to the quality of the artificial stone, made with a silica base, 70.—Vote of thanks to, 74.—Appointed one of the auditors of accounts, 74.

Obituary of deceased members, 7.

Officers, 1848, list of, 56.

Original communications, instructions for preparing, 26.—Ditto received between June 30, 1846, and June 29, 1847, 44.

——— drawings received between June 30, 1846, and June 29, 1847, 46.

Palmer, H. R., extracts from his "Report on the proposed eastern entrance to the London Docks," including remarks on the entrances to the Bristol and the Runcorn Docks, on the docks in the Port of London, and on the entrances to the principal public docks, and the labour entailed at the graving-docks on account of their position, 165.

Pasley, Maj.-Gen., remarks as to the injury sustained by the sea-wall along a portion of the South Devon Railway, 192.—Ditto as to the depth to which the action of the waves extends, 198.—Ditto as to his preference for vertical walls, as sea-defences, in deep water, the materials of which they should be composed, and the method of building, 411.—Ditto as to the unsteadiness of diving-bells, 414.

Pellatt, A., remarks as to the manufacture of artificial stone, with a silica base, 61, 65.—Ditto as to the difficulty of making large articles of terra-cotta, 63.

Penrose, F. C., elected associate, 250.

Peto, S. M., M.P., remarks as to nuisances likely to arise from spreading liquid manure over land near towns, 94.

Phillips, R., remarks as to experiments upon the chemical nature of the artificial stone, manufactured with a silica base, 68.

Piston, elastic metallic, Mather's, notice of, 289.

Pole, W., remarks as to the quantity of rain falling, in the same locality, at different levels, on the Malabar coast of India, 281.

Premiums, Telford medals, and Telford and Council, awarded, Session 1847, 2, 22, 74.—List of subjects for, Session 1848, 23.—Extracts from the Minutes of Council, Feb. 23, 1835, on the principal subjects for, 26.

Presents, falling off in, noticed in Annual Report, 5.—Catalogue of, received between June 30, 1846, and June 29, 1847, 47.

Public works, remarks in the address of Sir J. Rennie, President, as to, coming under the control and cognizance of the Government, 30.

Railway, atmospheric, proposed series of experiments upon the, noticed in the Annual Report, 16.

Railway junctions, on, 204.—New method of setting out, 204.—Tables to facilitate ditto, 208.—Discussion on ditto, including remarks as to Mr. Wild's switch, 210.

Railway money chest, notice of a, 185.

Railway trains, resistances to, at different velocities, observations on the, (abstract) 292.—*Vide* also Resistances.

Rainfall in different parts of England, the amount lost by evaporation and absorption, and the quantity flowing off the ground, remarks as to the, 275 *et seq.*

Rain-gauges, proper position for placing, remarks as to the, 277.

Rankine, W. J. M., account of the effect of the storm of the 6th of December, 1847, on four sea-walls, or bulwarks, of different forms, on the coast near Edinburgh; as illustrating the principles of the construction of sea-defences, 186.—Remarks as to sea-walls, 199.

Ransome, F., on the manufacture of artificial stone, with a silica base, 57.—Remarks as to ditto, 59.—Ditto ditto, and its comparison with terra-cotta, 64, 65.—Ditto as to the power of the artificial stone to resist pressure, 68.—Elected associate, 184.

———, R. T., remarks as to the production of architectural ornaments, and other works of art, in artificial stone, made with a silica base, 65.

Rawlinson, R., elected associate, 184.

Redman, J. B., appointed one of the scrutineers of the ballot for Council, 73.—Vote of thanks to, 75.—An account of the Maplin Sand Lighthouse, at the mouth of the River Thames, 146.—On the formation of entrances to wet and dry docks, situated upon a tideway; illustrated by the principal examples in the Port of London, 159.—Remarks as to ditto, particularly as to the West India, the London, and the St. Katharine's docks, and as to the best angle for a wall along which a vessel has to pass to enter a lock, 173, 182.—Ditto as to the Ipswich docks, 179.—Ditto as to proposed wet dock, 183.

Rendel, J. M., *V. P.*, remarks as to the employment of artificial stone in works of construction, 68.—Ditto as to dock-entrances, 181.—Ditto as to sea-walls, and as to comparison of those on the coast near Edinburgh, and on the coast of Devonshire, 196.—Ditto as to the difficulty of protecting the toe of the wall, 195.—Ditto as to the depth to which the action of the waves extends, 198.—Ditto as to the accuracy of his estimate of the vacuity in the Plymouth Breakwater, 409.

Rennie, G., remarks as to screw-piles, 141.—Ditto as to dock-entrances, 175.—Ditto as to the action of the sea on banks, such as the Chesil Bank, and as to the question of the translation of shingle, 361.

———, Sir J., *President*, address of, to the annual general meeting, 27.—Remarks as to the balloting list for the members of Council, particularly as to the bien-

nial change of President, and as to the nomination of Mr. Field for that office, 27.—Necessity for making the Institution the depository of communications, written or oral, descriptive of executed works, 28.—As to public works coming under the control and cognisance of the Government, 30.—Vote of thanks to, 74.—Remarks as to the contemplated sites for, and modes of construction of, harbours of refuge, 402.—Ditto as to the Plymouth Breakwater, 402, 414.—Ditto as to the harbours of Kingstown, Howth, Ardglass, Portrush, and Dunmore, 405.—Ditto as to Cherbourg Breakwater, 408.—Ditto as to the proposed refuge harbour in Dover Bay, 408.

Report, Annual, 1.—Principal original communications read during the past session, 1.—List of Telford medals, and Telford and Council premiums of books awarded for ditto, 2.—Notice of some of the principal Papers, 3.—Objects of the Institution can only be sustained by the presentation of Papers for reading at the meetings, 5.—Falling off in presents of books, maps, &c., 5.—Tabular statement of the transfers, elections, deceases, and resignations of members of all classes, during the years 1846 and 1847, 6.—Ditto of the annual increase of members and associates during the past six years, 6.—Obituary of deceased members, 7.—Subscriptions to the building-fund, 15.—Statement of arrears of subscription for 1847, and for previous years, 15.—Loss by failure of bankers, 16.—Proposed series of experiments upon the atmospheric railway, 16.—Unauthorized publication of the drawings illustrating, and extracts from, Mr. Bateman's Paper, "Description of the Bann Reservoirs," 17.—Remarks as to the balloting-list for the members of Council, 18.—Useful suggestions made in the course of the discussions at the meetings, 18.—Abstract of receipts and expenditure from the 1st January to the 31st December, 1847, 20.

Resistances to railway trains at different velocities, observations on the, (abstract,) 292.—Mode of conducting the experiments, 292.—The deductions from Mr. Wyndham Harding's formula reviewed, 293.—Other resistances besides those of the atmosphere, with the amount of the latter, 293.—Elements to be determined by experiments, before any general formula can be made, 293.

Reynolds, J., memoir of, 12.

Richmond, J., description of an engine-counter on an improved principle, 71.

River improvements—the engineering of the Rhine, including a translation of M. Van den Bergh's Paper, on the improvements of the Moselle, 211.—Rise and course of the Rhine, and geological character of its bed, 211.—Table of the levels, widths, slopes, and depths of the Rhine, from its source to Holland, 214.—Table of the velocities and quantities of water in ditto, 215.—Table of the levels, widths, slopes, and depths of the Rhine, through Holland to the sea, including the levels of the dykes, 216.—Table of the velocities and quantities of water in ditto, 218.—Depths at high water, and at floods, in different years, 219.—Lowest waters in different years, 219.—Effects upon the level of the Rhine produced by the tributary streams, 219.—List of the places where the principal breaches in the dykes have occurred, since 1421, 220.—Result of floods and inundations along the Rhine, 221.—On the construction of the present works on the Rhine, 221.—The French district, from Bâle to Lauterburg, 221.—Dams for closing up arms of the river, constructed with fascine bundles and solid basket-work, 222.—Dam at Rankopf, 222.—Shore-preserving works, consisting of parallel walls and spurs, 224.—The Prussian district, from Lauterburg to Emmerich, 225.

—Shore walls on ditto, 225.—On the improvements of the Moselle, being the translation of a Paper by M. Van den Bergh, 226.—Description of the river, 226.—Principal object aimed at in the proposed improvements of straightening the stream, and contracting it by a system of spurs, 227.—Weirs for damming-up arms in the stream, 229.—Lighter works, constructed chiefly of fascine work, to further contract the stream, 229.—Stone walling for preserving the shores between Cologne and Düsseldorf, 231.—Mode of construction adopted by Wiebeking, for a system of down-stream spurs, 232.—Dam erected by Wiebeking, in 1790, at the Island of Honneff, close to Bonn, 232.—Outlet of the Sieg, 232.—Shore-covering, or arming, at Flehe, 233.—Shore-walling at Grimlingshausen, 233.—Improvements of the Ruhr, below this to Emmerich, beyond by the Byland cut, or canal, and new outlet at the Yssel, near Arnhem, 234.—Pannerden Canal, at the first division of the Rhine below Lobeth, 234.—Drainage of lands throughout Holland, and method adopted for getting rid of the inland waters, 234.—Fascine spurs and arming on the Dutch Rhine, the Waal, the Leck, and the Meuse, above the reach of the tide, 235.—Action of the tides on the lower portion of the river, 236.—Table giving the results of the experiments of Blanken on the tides, 1796-7-8, 238.—Table, given by Bolstra, of distances and slopes up which the tide travels, 238.—Table giving the results of the experiments instituted by Bolstra, for ascertaining the average rise of tide and ebb in the Old and New Meuse, and in the Merwede, during 1739-40-41, 239.—Table showing the duration of the ebb and flood in the Meuse and the Merwede, 240.—Table showing the heights of the crown of the dykes along the Rhine, the Waal, the Leck, the Yssel, and the Meuse, above the highest floods, 240.—Proposals to effect the letting off the surface-water of the Leck, 241.—Frequent ice-stoppages on the streams running through Holland, and system of improving the rivers in that county, 242.—Object to be aimed at, for improving the Meuse at Rotterdam, 243.

Rivers and harbours, observations on the causes that are in constant operation tending to alter the outline of the English coast, to affect the entrances of the, and to form shoals and deeps in the bed of the sea, 327. *Vide* also Coast.

Robinson, Lieut. F., R.N., remarks as to the screw-pile lighthouse at Fleetwood-on-Wyre, 140.

Russell, J. Scott, remarks as to the applicability of the screw-piles for forming an open breakwater, 142.—Ditto as to dock entrances, 181.—Ditto as to sea-walls, having reference particularly to some on the coast near Edinburgh, 196.—Ditto as to the system of spurs on the Dee, in Cheshire, 244.—Ditto as to the effect of long oblique weirs for improving the regime of a river, and as to the plan adopted in the Clyde, 245.—Ditto as to the resistances to railway trains, and as to the mode of conducting experiments for ascertaining the, 294, 322, 326.—Ditto as to experiments on inclined planes, 305, 318.—Ditto as to the power of translation of the tide-wave, 363.—Ditto as to the principle to be kept in view in the improvement of channels and estuaries, 365.—Ditto as to the relative advantages of vertical, or sloping walls, as sea-defences, 414.

Saunders, G. H., elected associate, 184.

Scott, M., elected associate, 75.

Screw-pile and moorings, on submarine foundations, particularly the, 108.—Circumstances which led to the introduction of the screw-pile and the screw-mooring, 109.—Proper area of the screw, 110.—Span-chain mooring, 110.—Sinker, or mooring-block, 112.—Modification of the screw-pile for holding down the buoy-chain, 113.—Comparative masses of ground which must be removed in dragging up a sinker, or mooring-block, and the screw-pile mooring, 114.—Comparative cost of screw, span-chain, and common stone moorings, 115.—System of screw-moorings in the Tyne, and apparatus employed for fixing them, 115.—Purposes to which the screw-pile has been applied, 117.—Beacons upon the banks and shoals at the entrance of the Thames, 117.—Proposal for placing a fixed light on the Dumball, at the entrance of the Avon, 117.—Foundations of the Maplin Sand Lighthouse, 118.—Instrument used in trying the nature of the ground, and in testing its holding power, 118.—Raft employed in fixing the foundation piles for the Maplin Sand Lighthouse, with the cost, 119.—Lighthouse erected on screw-piles at Fleetwood-on-Wyre, 119.—Description of the locality, 120.—Captain Denham's opinion of the Fleetwood and Wyre Seaward Lighthouse, 120.—Situation selected for the lighthouse, with details of the structure and of its cost, 121.—Comparative merits, and expense, of fixed and floating lights, 122.—Screw-pile lighthouse in Belfast Lough, 123.—Attempt to place a screw-pile lighthouse on the Kish Bank, 123.—Screw-pile beacons on the Kish, the Arklow, and the Blackwater Banks, 124.—Screw-pile beacon between the Queen's and Prince's Channels in the Thames, 125.—Comparative advantages of beacons and marking-buoys, 125.—Screw-pile pier, or jetty, at Courtown, 126.—Method of construction, 128.—Dimensions of the work and expense, 128.—Distinguishing features of such piers or jetties, 129.—Cast-iron screw socket-points, for whole-timber piles, and their applications, for railway signal-posts, for electric-telegraph posts, and for tent-pins, 129.—Instance of the stability and the power of holding of these screw-points, 131.

Screw-propeller, remarks as to the application of the, to steam navigation, noticed in the address of Mr. J. Field, President, 42.

Sea-walls—account of the effect of the storm of the 6th of December, 1847, on four sea-walls, or bulwarks, of different forms, on the coast near Edinburgh; as illustrating the principles of the construction of sea-defences, 186.—Sea-wall of the Leith Branch of the Edinburgh and Dalkeith Railway, 187.—Ditto on the turnpike-road between Newhaven and Trinity, 189.—Ditto of a portion of the Edinburgh, Leith, and Granton Railway, 190.—Ditto ditto, at and near Granton, 190.—Efficiency of the surface of a wall to resist the action of the waves, 190.

Sewage-manure, remarks as to means for rendering it available for agricultural purposes, and instances of its application, 87, *et seq.*

Sewerage and drainage of Bristol, account of the recent improvements in the, 76.—Results arising from the formation of the floating harbour, in 1805, 76.—New sewer from the Froome, passing under the bed of the float, and delivering itself into the new cut made for the Avon, 77.—Characteristics of the River Froome, 77.—State of the Froome, arising from the sewerage, and measures necessary for abating the nuisance, 79.—Works directed to be carried into execution, 80.—Order of execution, and cost of the works, 82.—Benefits the works have produced, 84.

Shingle, sand, &c., motion of. *Vide* Coast.

Shingle, best direction for the construction of groynes for the collection of, 344.
———, remarks as to the accumulation of, by groynes, 199.
Shipbuilding in iron, noticed in the address of Mr. J. Field, President, 35, 39.
Shipwreck, causes of, report from the Select Committee of the House of Commons, in 1836, as to the, 366.
Simpson, J., *V.P.*, remarks as to engine-counters, 72.—Ditto as to the sewerage of towns, 94.—Ditto as to the works for the improvement of the River Tees, 246.
Smith, —., remarks as to the screw-moorings in the Tyne, 143.
Smith, C. H., remarks as to the manufacture of artificial stone, with a silica base, and as to the warping and shrinking of terra-cotta ornaments in the process of baking, 61.—Ditto as to the specific gravity, or weight, of different building-stones, 200.
Smith, F. P., elected associate, 250.
Smith, J. (of Deanston), remarks as to means for rendering available for agricultural purposes the sewage-manure of towns, 87.—Ditto as to the applicatio of sewage-water on some meadow ground near the city of Edinburgh, on the Duke of Portland's estate, near Mansfield, and on a farm near Glasgow, 88.—Ditto as to means of disposing of the sewage-water of London, 89.
Spence, T. B., remarks as to Messrs. Tebbutt's establishment, Limekiln Docks, and as to the entrances to wet docks, 177.
Steam-navigation, application of the steam-engine to navigation, noticed in the address of Mr. J. Field, President, 35.—Progress of the marine engine and steam-navigation, ditto, 38.—High speed attained by the introduction of the tubular boiler, ditto, 40.—Reduction in the consumption of fuel, ditto, 42.—Introduction of the screw-propeller, ditto, 42.
Stephenson, R., M.P., *V.P.*, remarks as to the manufacture of artificial stone, with a silica base, and as to the use of that material for architectural ornaments, 63.—Ditto as to the resistances to railway trains, as to the mode of conducting experiments for ascertaining the, and as to experiments on inclined planes, 314, 320, 324, 325.
Stone, artificial, on the manufacture of, with a silica base, 57.—Description of the process, 57.—Changes which take place during the operation, 58.—Chief peculiarity which distinguishes this from other artificial stones, 58.—Experiments upon its strength, 59.—Remarks as to its durability, 59.
Stones, building, remarks as to the specific gravity, or weight, of different, 200.
Subscriptions, arrears of, statement of, for 1847, and for previous years, 15.
Submarine foundations, on, particularly the screw-pile and moorings, 108. *Vide* also Screw-pile.

Tabular statement of the transfers, elections, deceases, and resignations, of members of all classes, during the years 1846 and 1847, 6.—Ditto of the annual increase of members and associates for the past six years, 6.
Taylor, J., remarks as to the destruction of cast-iron pump-trees when exposed to the action of mine-water, 158.
Taylor, John, elected associate, 366.
Taylor, P., remarks as to the change suffered by cast-iron when in contact with gun-metal, 158.—Ditto as to the decay of cast-iron in coal-mines, 158.
Telford medals, and Telford and Council premiums of books awarded, Session 1847, 2, 22, 74.—List of subjects for, Session 1848, 23.
Terra-cotta, remarks as to, and its comparison with the artificial stone, made with a silica base, 62, *et seq.*

Thom, R., memoir of, 7.
Thomson, J., remarks as to the foundation for, situation of, and materials for the construction of, sea-walls, as affecting the design, 197.—Ditto as to the resistances to railway trains, 325.

Underwood, Col., remarks as to situations where the screw-pile would be invaluable, especially on the coast of Coromandel, 145.
Ure, Dr., remarks as to chemical preparations for neutralizing and destroying noxious effluvia, and counteracting putrescence, 97.—Ditto as to the nitrate of lead process of M. Ledoyen, 98.—Ditto as to the chloride, or muriate of zinc, process of Sir W. Burnett, 98.—Ditto as to peroxide of iron, and protoxide of manganese, 98.—Ditto as to researches into the composition of the excrement of animals, 99.—Ditto as to Sir Humphry Davy's investigations on gas-lighting, 99.

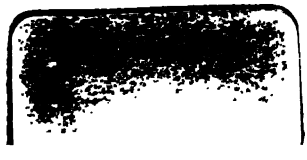
Valentine, J. S., elected member, 326.
Van den Bergh's (M.) Paper on the improvement of the Moselle, translation of, 226. *Vide* also River Improvements.
Vardon, R., elected member, 326.
Vignoles, C., remarks as to the Fleetwood-on-Wyre and Maplin Sand Lighthouses, 156.

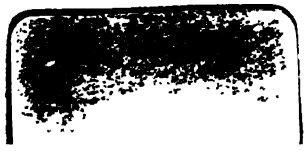
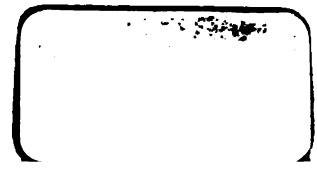
Walker, J., remarks as to the manufacture of artificial stone, with a silica base, 67.—Ditto as to its use for building purposes, 69.—Ditto as to the drainage and sewerage of the metropolis, 104.—Ditto as to the size of sewers, 106.—Ditto as to screw-moorings, and as to the use of screw-piles for the foundations of lighthouses, 136.—Ditto as to a beacon on the Goodwin Sands, 136.—Ditto as to the construction of lighthouses, and especially of those upon the Bishop Rock and at the Point of Ayr, 137, 143.—Ditto as to the holding power of screw-moorings, 143.—Ditto as to the Maplin Sand Lighthouse, 155, 156.—Ditto as to gun-metal lantern for Point of Ayr Lighthouse, 158.—Ditto as to dock-entrances, 175, 179.—Ditto as to the forms of construction of sea-defences, with observations on the Plymouth Breakwater, and on the rising of seas against nearly vertical walls, 202.—Ditto as to rain-gauge experiments, 281.—Ditto as to large impounding reservoirs being applied to all large towns, 286.—Ditto as to the indifference of mercantile shipowners to the formation of harbours of refuge, 399.—Ditto as to Plymouth Breakwater, 399.—Ditto as to the accumulation of shingle, and the deposition of silt at Dover, 400.—Ditto as to the relative merits of vertical, or sloping walls, as sea defences, and the comparative expense, 401, 415.
Ward, J., elected member, 326.
Washington, Capt., R.N., remarks as to screw-pile lighthouses on the Maplin Sand, at Fleetwood-on-Wyre, and at Belfast, 139.—Ditto as to the screw-moorings in the Clyde, the Humber, and the Tyne, 139.—Ditto as to the comparative merits and expense of floating and fixed lights, 139.
Water supply to towns promoted by the practical aid of the mechanic, noticed in the address of Mr. J. Field, President, 36.
——— valves, notice of Lambert's flexible diaphragm, 416.
Watson, J., elected associate, 326.
Waves, Mr. Alan Stevenson's marine dynamometer, for testing the force of the, 396.

Waves, nature, action, and strength of, 329, *et seq.*, and 394, *et seq.*
Welbank, Capt., remarks as to screw-piles and moorings, 138.—Ditto as to beacons, caissons, and lighthouses, proposed for the Goodwin Sands, 138.—Ditto as to statement, that lightships were in the habit of parting their moorings, 139.
Westminster, the Very Rev. the Dean of, remarks as to the manufacture of artificial stone with a silica base, and as to the experiments of Humphry Watt and Sir John Hall in that direction, 66.—Ditto as to the nuisances arising from the defective drainage of Bristol, 84.—Ditto as to flushing the metropolitan main sewers, 85.—Ditto as to the lighting of metropolitan thoroughfares, and as to the best form of gas-burner, 85.—Ditto as to the use of various deodorizing fluids, when emptying cesspools, 92.—Ditto as to evils arising from open sewers, 93.—Ditto as to the application of liquid manure for agricultural purposes, especially on the Duke of Portland's estate, near Mansfield, and on some meadow land near Edinburgh, 93.—Ditto as to proposal for establishing a manufactory of 'poudrette,' 94.—Ditto as to the Cob Wall, at Lyme Regis, 202.—Ditto as to the importance of a knowledge of geology to Civil Engineers, 243.
Wicksteed, T., remarks as to engine-counters, 73.—Ditto as to plan for the advantageous use of the products of sewers, 90.—Ditto as to plan for using the sewage-water of London, 90.—Ditto as to system proposed for the sewerage of Berlin, 91.—Ditto as to the sewerage of towns, and as to utilizing the products of the sewers, 103.—Ditto as to the proposition for substituting circular sewer pipes, of small diameters, for the present sewers, 103.
Wild, C. H., elected associate, 75.—Remarks as to his railway switch, 210.
Wilkins, W., remarks as to the effects of gales of wind on the Edystone and the Maplin Sand Lighthouses, 155.
Wood, S., elected associate, 250.
Wright, J., appointed one of the auditors of accounts, 74.
Wyatt, T. H., vote of thanks to, 74.

Young, Sidney, remarks as to the most convenient angle to the flow of the tide for placing dry docks, and as to the entrances of wet docks, 176.

LONDON:
PRINTED BY W. CLOWES AND SONS, STAMFORD STREET
AND CHARING CROSS.





LONDON:
PRINTED BY W. CLOWES AND SONS, STAMFORD STREET
AND CHARING CROSS.